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ABSTRACT

This book discusses building commissioning, which is the process of certifying that a new facility meets the required specifications. As buildings have become more complex, the traditional methods for building start-up and final acceptance have been proven inadequate, and building commissioning has been developed, which often necessitates the use of outside consultants to monitor the process. One-half of the guide details the roles of the consultant, contractor, test engineer, commissioning agent, and owner. It describes the process, the needed equipment testing, systems functional performance testing, scheduling, documentation, training, costs, and the process of hiring a commissioning agent. Chapters include an overview of commissioning and discussions of: approaches to commissioning, design requirements, contract documents requirements, the steps of the commissioning process, selecting the commissioning agent, and the costs of commissioning. A case study of commissioning a science building is provided. The other half of the guide consists of a description of terms and 15 different guide specifications in the form of detailed documentation and testing checklists, divided to indicate specific tasks and tests (e.g., general, mechanical, electrical facility startup/commissioning; commissioning--general requirements; HVAC systems, supply air systems, exhaust air systems, environmental control systems, etc.) (JLS)

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The Association of
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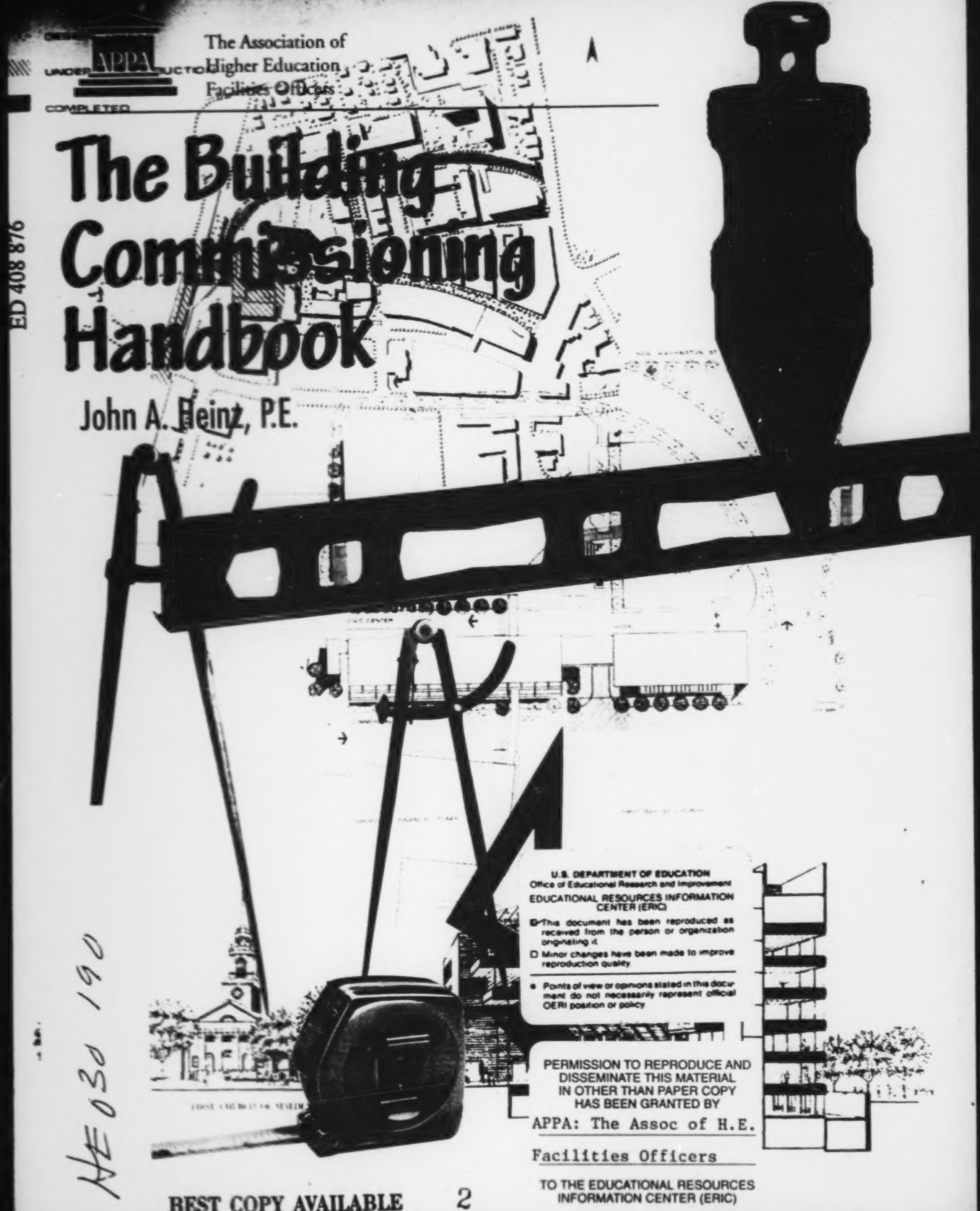
Facilities Officers

The Building Commissioning Handbook

John A. Heinz, P.E.



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The Building Commissioning Handbook

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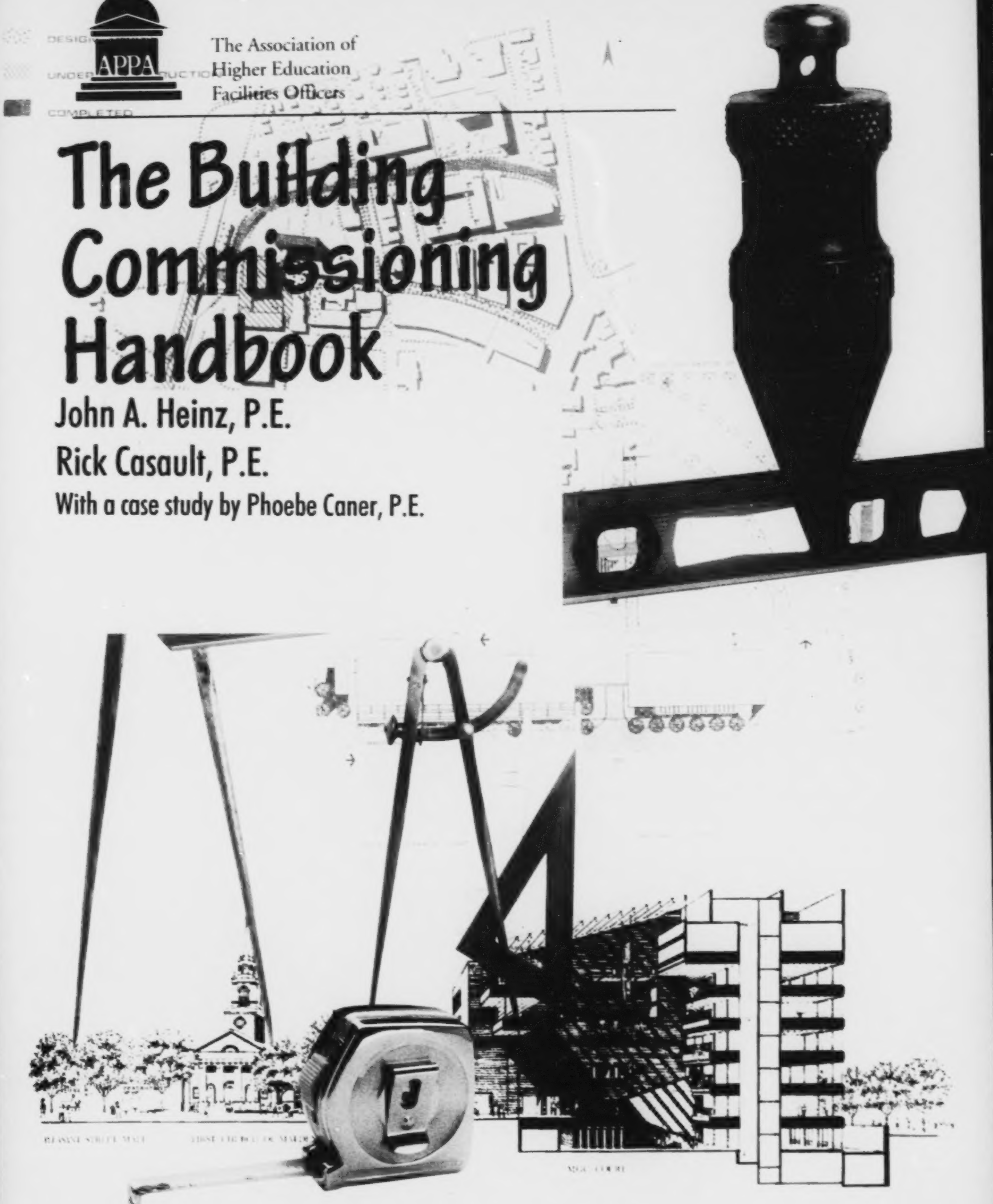
With a case study by Phoebe Caner, P.E.


DESIGN
UNDER CONSTRUCTION
COMPLETED

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❖ Preface

There is a certain class of complex building designs which, in all likelihood, simply will not work unless a formal building commissioning program is properly employed. This reality applies to all institutions, both large and small, particularly when constructing a complex science building with variable air volume (VAV) heating, ventilation, and air conditioning (HVAC) systems, perhaps with VAV fume exhaust systems, energy conservation systems, and distributed digital control (DDC) environmental control systems. For the small college, which may not have the luxury of a technically strong operations staff, commissioning could easily be the most important part of the project—notwithstanding quality design and quality construction.

I made my first presentation regarding building commissioning at the annual meeting of the Pacific Coast Region of APPA: The Association of Higher Education Facilities Officers in September 1991. The audience was attentive but perhaps less than enthusiastic. Building commissioning was not well defined then, and most attendees probably felt already overburdened with existing facilities operation requirements and unstable budget conditions; they didn't need a new issue to develop and promote. I felt, however, that it was time to begin educating my colleagues on the process in preparation for the time when building commissioning would be a truly critical component in the overall process of facilities development. That time has come.

Since it is predictable that maintenance and operations funding will continue to diminish, a capital construction program *must* turn over to the operations staff a fully functional facility. There are too many horror stories about new facilities with problems that took several years to wring out; sometimes never to operate to the expectations of the design intent. Such incidents are unacceptable.

Maintenance and operations program funding is not intended (and cannot be expected) to save dysfunctional buildings. The reasonable alternative is to require the capital program to formally commission each new facility and deliver a fully functional building to the owner.

For the institution, commissioning must be a comprehensive, all-inclusive process. The whole building must be taken through a series of functional performance tests. It is not good enough to commission only one aspect of the building.

For the institution, commissioning must be a comprehensive, all inclusive process. The whole building must be taken through a series of functional performance tests. It is not good enough to only commission one aspect of the building.

In that regard, electrical utilities are promoting commissioning and offering such services, with the goal of optimizing the operation of the energy conservation measures incorporated in the design (some of which may have been funded by local utilities). However, such a program does not usually result in a comprehensive commissioning of the whole building.

Similarly, there are commissioning workshops focused on HVAC systems. Whereas that may be the major component of building commissioning, it is far from a complete program. Functional performance testing must include the interaction of the HVAC systems with the life safety systems, emergency power provisions, and so forth.

At the University of Washington, our experiences with constructing four sophisticated new science buildings within a relatively short span of time led us to develop a comprehensive commissioning program for new buildings. Unfortunately, we started too late to incorporate properly commissioning requirements in the design professionals' agreements or in the construction contract documents for these buildings.

However, each facility includes some aspect of commissioning, and we have gradually and significantly refined our requirements. Construction contract documents for new buildings being designed now include extensive documentation regarding system and equipment performance expectations, design criteria, and commissioning requirements specific to the prime and subcontractors, the commissioning agent (firm), and the owner.

So, just what is commissioning? Commissioning is a programmed series of design and construction documentation and testing activities that are performed specifically to ensure that the finished facility operates as intended.

So, just what is commissioning? Commissioning is a programmed series of design and construction documentation and testing activities that are performed specifically to ensure that the finished facility operates as intended; in short, making it work. While it is a complex process, it is easy if one begins at the beginning and proceeds with determination and the cooperation of consultants and contractors to develop a smooth running program.

Before proceeding, I wish to offer another word of caution: The shortcoming of doing a book on commissioning is that building commissioning, just like building design and construction, must take into consideration the culture of the local design and construction community, as well as local traditions, in applying the processes recommended in this book. The perspective presented here relates to my environment. In the commissioning workshops, participants introduce a range of variations induced by regional conditions. It is easy in the workshop setting to suggest alternatives; that interaction is unfortunately absent in a book.

With that caveat, this book presents, in detail, the roles of the consultant, contractor, test engineer, commissioning agent, and owner. These include subcontractors, vendors, subconsultants, owner's operations staff, and testing, adjusting, and balancing firms, all of whom have a stake in the total effort. This book discusses the commissioning process, equipment testing, systems functional performance testing, intersystem functional performance testing, scheduling, documentation, training, costs, advertising for and selecting a commissioning agent, and anything else that comes to mind along the way. By the end of this book, you should be convinced that building commissioning is not only important for the success of your capital construction program, but also that the cost of building commissioning is far less than the long-term cost of not commissioning your new facilities.

For many institutions, building commissioning could be one of the most important new ventures for the facilities officer. It should be considered an inexpensive insurance policy, specifically designed to avoid taking over a dysfunctional facility. If you have not had previous building commissioning experience, the information in this book will provide you direction toward developing an effective building commissioning program.

—John A. Heinz, P.E.
Seattle, Washington

❖ Chapter 1

An Overview of Commissioning

As institutional and commercial buildings have become more complex, the traditional methods for building start-up and final acceptance have proven inadequate. The increased complexity of building systems is a response to energy conservation requirements, to the need for safer work environments, to demands for improved indoor air quality and better comfort control, and to technological advancements in teaching and research methodologies. Distributed digital control systems help to meet these needs but add sophistication and complexity. Thus, the entire process of acquiring new facilities must also become more sophisticated in order to keep pace with the complexity of new technologies and to get the required performance from them.

The failure of traditional building start-up methods, combined with the health, safety, and energy consequences of failure, is the impetus driving adaptation of the commissioning philosophy to institutional facilities. While the process of commissioning is relatively new to commercial and institutional building construction, it is modeled from commissioning industrial facilities and naval ships. Industrial facility controls are dry-lab tested extensively before installation in the facility. After installation, equipment and controls are further tested and calibrated to ensure that production starts up on schedule and continues with maximum operational reliability.

Similarly, components and systems on naval ships are tested at dockside and then pushed to the limits during sea trials. Commissioning attempts to break whatever is prone to failure and to discover whatever design and installation errors exist. The serious consequences of failure in naval and industrial systems drive the effort to systematically wring out problems before systems are brought on line.

Commissioning attempts to break whatever is prone to failure and to discover whatever design and installation errors exist.

Commissioning, as it applies to institutional and commercial construction, is in the early stages of development. It may be many years before commissioning matures to the point that it is well understood by design consultants and contractors. In the meantime, those on the vanguard will continue to develop the commissioning industry to ensure that new institutional facilities are brought on-line operating to the client's expectations.

Definition

An all-inclusive definition for commissioning has not been universally adopted. The definitions most often reflect the specialty within a facility that is being commissioned. Electrical utilities concentrate on and fund energy conservation measures to optimize energy consumption. Local fire departments concentrate on commissioning fire and life safety provisions required by related codes. Other regulatory agencies insist that provisions within their jurisdictions be proven fully operational in accordance with their specific requirements.

As these narrow definitions persist, they negatively affect a proper understanding of the comprehensive requirements for commissioning an entire facility. Whereas utilities and regulatory agencies focus attention on commissioning certain systems, the owner must be assured that all systems within the facility have been commissioned. For hospitals and other health care facilities, commissioning is imperative. Commissioning is a requirement for high technology laboratories and research facilities. It is also important for classroom and office buildings to meet the specific and diverse needs of the occupants. Hence, commissioning calls for a broad definition.

The building owner views the entire building as a *system*—a system that must meet a wide range of occupancies and functional needs. The definition from the summary report from the 1993 National Conference on Building Commissioning is appropriate:

> *Commissioning is a systematic process of assuring that a building performs in accordance with the design intent and the owner's operational needs.*

Another relevant term (virtually synonymous) is "discovery." Commissioning is a process that ensures discovery of flaws in the design or construction that will prevent the facility from operating in accordance with parameters set by the owner. Such problems inevitably will be discovered, but usually under the most unfavorable circumstances, resulting in operating difficulties that could be critical or, in the extreme, even fatal. At best, these discoveries will inconvenience building occupants and maintenance and operations staff. Commissioning forces the discovery of flaws under controlled conditions, at a time when dire consequences are least likely.

Further, if discovery reveals problems before the construction contracted is accepted as complete, the consultants and contractors will bear the burden of taking corrective action and all related costs. Failures discovered later become the burden of the owner, who has little or no recourse back to those responsible.

Goals

The overall goal of building commissioning is to produce a facility that operates as intended. However, it is important to recognize several specific subgoals that will be achieved as a direct result of the commissioning process.

The first subgoal is to provide a safe and healthy facility for students, faculty, staff, and the public. Commissioning minimizes functional and operational deficiencies that have been shown to be responsible for the majority of indoor air quality problems and comfort complaints. Commissioning minimizes liabilities inherent in laboratory building operations.

The second subgoal is to improve energy performance. Commissioning is the "tune-up" that gets the most efficient performance out of the installed equipment. Commissioning tailors system operating parameters to the conditions of actual usage. Commissioning optimizes system performance to meet the requirements of the conditions, rather than simply operating at the capacity of the equipment.

The third subgoal is to reduce operating costs. Equipment operating improperly is operating inefficiently. Improper operation usually induces more frequent maintenance activity and results in shorter life expectancy for the equipment. Annual operating costs increase and capital replacement costs occur more frequently.

Six subgoals of building commissioning are:

1. To provide a safe and healthy facility for occupants.
2. To improve energy performance.
3. To reduce operating costs.
4. To improve orientation and training of staff.
5. To improve facility documentation.
6. To ensure the facility meets the client's needs.

The fourth subgoal is to improve orientation and training of the operations and maintenance staff. The sophisticated systems being installed will be disabled if operations and maintenance staff do not understand operation and maintenance requirements. No matter how well the equipment and systems are operating at the onset, systems will degenerate without proper care. Designers and contractors can barely keep up with the proliferation of "high tech" system configurations and associated equipment and controls. Without design documentation, explicit diagrams and operating procedures, and effective training, operations and maintenance staff will soon flounder.

The fifth subgoal is improved documentation. Traditionally, specifications and drawings do not provide all of the information that will be needed for operation, troubleshooting, and renovation of the facility. Design intent documentation, one-line diagrams, and operating descriptions help to communicate the designers' intentions to current and future operators and designers. Fully documented testing procedures and results verify the capacity and operating parameters of the facility and systems, and facilitate recommissioning as needed in the future.

The sixth and most important subgoal is to meet the clients' needs. When the design and construction of a facility is systematically scrutinized and verified, the overall result is a facility that operates as intended, to the clients' satisfaction.

Process

Once it is recognized that an entire building, including all systems therein, must be commissioned, a very specific, highly disciplined process begins. Commissioning starts at the construction phase with developing an inventory of all of the systems and components to be tested and commissioned. From this inventory, component testing and system commissioning requirements are analyzed, and construction and testing schedules are adjusted to dovetail these processes with project completion dates.

Test procedures are then developed to ensure successful, full-range operation of each component. The integrity of the component-to-component interfaces are tested, followed with test operation of the components as a system, to verify that the components interact to meet performance expectations. System operation is configured for operation at the design extremes. This may require considerable ingenuity to replicate operating conditions that are expected to occur only occasionally. Finally, the interactive relationships of all systems that must interact are tested to ensure that each functions as intended.

In short, a tremendous amount of planning, preparation, test procedure development, and documentation is required in order to commission a building. However, if all steps are fully implemented, the payoff will be a building that actually operates as intended. The key to success is a strict discipline for thorough, sequential completion of the various test activities with detailed record keeping to verify that all testing has been performed as required.

In order for the preceding to be accomplished effectively there are several important steps that must occur during the design phases in order to 1) ensure that design parameters and performance expectations are properly understood by clients, contractors, and commissioning personnel, and 2) ensure that the contract documents clearly indicate testing and commissioning requirements placed upon the prime and subcontractors in regard to commissioning the building. Although the importance of engaging a qualified commissioning agent will become apparent, it is important that the responsibility for testing, verifying, and demonstrating the performance of the equipment and systems be placed on the contractors. This will have a direct effect upon the quality of the equipment provided, installation, and workmanship.

When Does Commissioning Start?

In many cases, commissioning may take place only during or following the construction period. This is particularly the case in situations where commissioning is not considered until after it is discovered that the new facility is not operating as intended. It is never too late to introduce commissioning; however, there is a great deal to be gained by starting much earlier in the process.

Ideally, commissioning should begin with the programming phase for the facility. Budget factors may make it necessary to postpone hiring a commissioning agent until later, but the project team should at least agree during programming that the facility will undergo commissioning. If functional issues are not addressed and documented at this stage, it is very difficult to achieve a key goal of commissioning: to meet the needs of the client. The client's needs must be clearly established during the programming phase of design.

When commissioning is introduced during the design or construction phases, the process will not be as smooth, but commissioning can still be initiated. You will need to negotiate revisions to contracts already in force to incorporate commissioning at these later stages. Generally, it is recommended that the services of a qualified commissioning agent be secured as soon as possible to guide the process, since, to a great extent, the traditional members of the design and construction team are not yet skilled in the commissioning requirements and processes.

Which Projects Should Be Commissioned?

Should every new facility be commissioned? The answer is yes. There is, however, a wide range available in determining what is critical and what may be considered optional. Certainly, facilities that, by definition, provide critical services to the institution and community should be fully commissioned. However, one can adjust the scope of commissioning as may be appropriate for simple buildings. Apply resources where they will do the most good. Typically, the first 20 percent of effort will correct 80 percent of the problems. That may be all that is required for a simple project.

On smaller or less complex projects, when budgets are tight, and where there are only limited risks associated with improper operation, commissioning functions may be performed by others without involving a commissioning agent. In some cases, the owner's staff may be capable of performing the function of the commissioning agent, guiding consultants in their role of specifying test criteria and witnessing execution of tests. Likewise, the consultant may be capable of reviewing the contractor's commissioning submittals on simple projects.

A key decision is identifying the best commissioning scope for a particular case. Should one apply full-scope building commissioning or should it be narrowed? Whether to pursue a narrowed scope of commissioning depends on one's assessment of the risks involved. Which risks should be evaluated? Clearly, health and safety are primary. Energy consumption should be considered for most projects. Political sensitivity, such as space being prepared for a high-profile faculty member, a project funded by a generous donor, or a project championed by the administration should receive careful consideration. A reduced or modified commissioning scope should be employed only when the perceived risk is low.

Can We Afford It?

The obvious concern is: How much is all of this additional effort and detail during design and construction going to cost? It is easy to jump to the conclusion that the commissioning process will inevitably increase the cost of projects. It is fair to say that at the onset there is likely to be some net increase in overall cost. However, experience proves that, when all costs of commissioning are compared with *all* costs of *not* commissioning, commissioning does not increase the owner's overall costs. Further, as consultants and contractors become more accustomed to commissioning, project costs may decrease.

Experience indicates that project management by the prime contractor is markedly enhanced by commissioning due to the increased discipline required to schedule the entire construction period around the process and the increased level of quality control it induces. The net result is tighter schedule control, better consideration of submittal materials, improved installation and workmanship, and so forth, resulting in a reduction in construction deficiencies and associated delays in completing construction. Testing, adjusting, and balancing (TAB) firms say that commissioning minimizes difficulties discovered during TAB, allowing them to quote lower costs for TAB work because it will proceed with measurably fewer difficulties. Similar efficiencies will accrue to all participants for like reasons.

❖ Chapter 2
Approaches to Commissioning

Before launching into detailed discussion of the many activities which, in the aggregate, comprise a comprehensive building commissioning program, it is important to recognize that there are many approaches to commissioning. There is no perfect, "one size fits all" approach because each client is unique and operates within the culture of the local design and construction community.

The approach advocated in this book is one that has worked well for the author, based on a number of local factors. This particular approach contains important safeguards for the owner. The building commissioning process must be adjusted and modified to suit the unique needs and circumstances of the client.

An Evolutionary History

Because building commissioning is a recent development, no vocabulary of terms exists that cleanly represents the various partner combinations that might be employed in the process. There are two primary variations of commissioning: single-party commissioning and multi-party commissioning. Within each of these there can be several more variations. Rather than attempt to invent a series of terms, it will be best to recount an evolution of experiences which lead to some recognition of different approaches one might take.

Commissioning At The University of Washington

Like most new programs, building commissioning arose from a need that has existed for some time. While the need for building commissioning was clear, there was no established experience base on which to draw, so the University of Washington developed its building commissioning program a little at a time, beginning in the middle.

Four sophisticated, complex science buildings were under construction or in late design phases at the same time. Within the engineering department, concern arose over the inadequacy of traditional start-up procedures. Over the years, each new building required more time to wring out problems and make it operate according to the intent of the design and the needs of the occupants.

Commissioning had been discussed and basic program requirements identified, but little had actually been done to integrate requirements into the design and the construction contract documents. Given the ongoing circumstances, however, the university felt it had no choice but to begin commissioning without the appropriate preparatory work. It was decided to engage the services of a building commissioning firm. That tentative beginning has evolved, several years later, into the program being employed today.

In the case of the first commissioning project, the building was already under construction when the commissioning agent was selected and engaged. Thus, the contractor was not aware that a commissioning agent would become a participant in the construction program. Because the contractor did not object to this late entry, everyone was relatively ignorant to the impact the commissioning program would have on the project.

The facility in this case was a 207,000 gross-square-foot, $35 million science building with variable air volume (VAV) supply, VAV nonrecirculating exhaust, VAV fume exhaust systems with over 200 fume hoods, and a direct digital control (DDC) building automation system. The design included operational diversities such that fans and primary ductwork were not sized for the aggregate total of all connected devices. This is a dynamic operation with virtually no identifiable, stable operating point. Hence, establishing an operating norm is virtually impossible. Operational success depends upon each controlling and controlled component operating exactly and predictably as intended. Anything less is intolerable.

It was said earlier that discovery is a synonym for commissioning. And discover we did:

- The VAV control for the fume hoods was disrupted by the through-wall sensor in the hood due to turbulence from the bypass, and was additionally influenced by impinging air temperature changes.
- Hundreds of actuators did not function through their full, cataloged operational ranges because extra lengths of connecting wiring created capacitance problems. Many actuators did not have sufficient power to move various components through the required range of operation.
- Many actuators initially worked successfully but after numerous cycles of operation began to slip on the shafts of the actuated device.
- Certain elements of design were not thoroughly thought through, resulting in some operational extremes that simply could not be met.

What became apparent through this experience is that too much is left to the interpretation and discretion of the contractor, subcontractors, and vendors. Consultants often don't analyze conditions that they think will rarely occur, and hence will not likely represent a serious problem. It was further apparent that none of these deficiencies would have become apparent until months (perhaps years) after the contractors and consultants were gone from the scene, at which point the university would be stuck with the problems. Even though the commissioning process appeared to disrupt the contractor's smooth, scheduled completion of the facility, the flaws it uncovered were more than worth whatever disruption it created. The underlying reality is that the design and construction included flaws which were the rightful responsibility of the consultants and contractors to resolve.

Because of the extensive discoveries and time required to consider and implement corrections and retest systems, the cost of the commissioning program increased considerably. The administration was rightfully concerned. However, that concern was offset by the magnitude and severity of problems that would have resulted without the commissioning process. The long-term probable cost to the owner, and the intangible impacts on research programs, would have exceeded the cost of the (ultimately) successful commissioning program.

Multi-party commissioning results in a "partnership" among the four primary parties: the contractor, the design team, the owner, and the commissioning agent.

The big lesson we learned was that we erred by not introducing commissioning into the project at the proper point in time—during programming and design. Had commissioning been included in the architectural agreement for the design team, and commissioning requirements and responsibilities included in the construction contract documents, it would not have caused such struggle and distress. This has been proven by subsequent projects, which benefited from this experience. What was most clear is that single-party commissioning is not the best choice of methods. It may, by default, be the only way to start in some cases, but should be avoided whenever possible.

The other three science building projects were each somewhat different. The fourth project included some requirements for the contractor regarding a commissioning program for the building. (This project is examined in detail in Chapter 8, Building Commissioning in Practice.) Although the process was much better, many further refinements are being incorporated in current projects; the most important refinement being adoption of the multi-party commissioning philosophy. Multi-party commissioning results in a "partnership" among the four primary parties: the contractor, the design team, the owner, and the commissioning agent. That partnership is induced through carefully and thoroughly stated contract requirements in the three contracts managed by the owner.

Ethical Considerations in Building Commissioning

Before discussing ethical considerations, it is appropriate to address two concerns frequently raised by associates. First, the suggestion that it is already the contractor's responsibility to produce a building that works; second, the idea that it is already the responsibility of the design team to make sure the building functions as intended. Whereas this may be true in some cases, it is certainly not the norm. There are many horror stories routinely told about dysfunctional buildings that have plagued owners long after the contractors and consultants have been released.

In the multi-party philosophy, the contractor and design team are partners, but neither one is the commissioning agent. Conflict of interest and several additional reasons preclude either serving in this role.

Some people recommend that the design team be the commissioning agent. First, consider the potential for conflict of interest. The owner wants to be assured that both construction and design flaws are discovered. Is it realistic to believe the design team is going to not only uncover design flaws, but also rush to the owner with these discoveries? Not likely. It is more likely that such discoveries will be returned to the consultants' offices to determine how to adjust system operation to approximate the intended operation, or to finesse solutions. It is healthier for all participants if the design team is not placed in what might be considered a compromising position.

Also, the division of responsibilities among design team members becomes unmanageable when so many complex components are described throughout the specifications. Who of those parties should take the lead in commissioning the various components and associated systems? Often it is not at all clear and, more often than not, it is a combination. Lastly, many design teams have not had extensive building operating experience—experience critical to understanding what actually is happening when things are not functioning as intended. Commissioning agents bring to the program in-depth operating experience, and that is much different from design experience. Not many designers have had a "career" of operating experience to apply to commissioning analyses.

Other people recommend that the contractor be the commissioning agent. Again, consider the potential for conflict of interest. Is it realistic to believe the contractor is going to uncover and report construction flaws? Not likely. In fact, all too often, contractors don't recognize construction flaws in the same sense that the owner recognizes them. Access is one of the most common flaws of concern to owners, but simply is not a high priority for most contractors. Beyond that, few contractors would be willing to admit that the workmanship or some materials or components supplied for the project may not be in accordance with requirements. It simply isn't realistic to put them into such compromising positions and try to hold them to such high standards of performance.

Also problematic is the implied expectation that the contractor understands the intricacies of the intended function of the systems *as systems.* Every system is different and it is unduly optimistic to assume contractors will understand enough to functionally test systems. Their expertise is construction, not operation. Commissioning agents have a range of diverse system operations experiences and can understand and evaluate system performance.

These concerns illustrate the need for the commissioning agent to be a third-party participant; a person or firm with no economic or political ties to either the consultants or the contractors. In order for the owner to be fully confident that he is finding out everything he needs to know about the building, the commissioning agent must be completely independent.

To summarize, single-party commissioning relies on the commissioning agent to perform the various commissioning functions. Multi-party commissioning requires participation of the contractor, design consultants, commissioning agent, and the owner. The latter places much of the responsibility for commissioning activities on the construction contractor, with verification by the commissioning agent. The designer specifies the commissioning process. The contractor coordinates, schedules, and executes testing under the direction of a test engineer hired by the contractor. The owner hires the commissioning agent to provide quality oversight for the entire commissioning process. These variables are discussed in more detail in the following sections.

Single-Party Commissioning

The design team plays a reduced role in single-party commissioning. They still document design intent and criteria and respond to the independent commissioner's review comments, but do not participate in specifying the process, though the contract documents must alert the contractor that the project will be commissioned.

Single-party commissioning requires little more of the contractor than is currently required without commissioning. The contractor corrects contract deficiencies as they are identified by the commissioning agent. The contractor may, however, manage quality differently if it is known the project will be commissioned.

The key player in single-party commissioning is the independent commissioning agent. The commissioner reviews design documents for compliance with program requirements, reviews the installation of equipment as construction proceeds, assembles project documentation, designs the commissioning testing program, executes the tests, reports deficiencies and recommends corrections, and issues a final commissioning report on the functional status of the facility.

Single-party commissioning adds a new player to the traditional owner/consultant/contractor team, but the functions of the design team and contractor remain much the same.

Multi-Party Commissioning

In multi-party commissioning, the architect leads the design team's participation in commissioning. Mechanical and electrical consultants play a key role in commissioning. The mechanical and electrical engineers write the design intent and design criteria to document the owner's functional requirements for the facility. They write the specifications for the contractor's participation in commissioning. They specify the commissioning test criteria.

Multi-party commissioning reduces the scope of work of the independent commissioning agent relative to single-party commissioning. The independent commissioner in multi-party commissioning reviews design and construction documents, verifies tests results, consults on problem solutions, and recommends acceptance of the final commissioning report.

Perhaps the greatest change in the traditional scope of work resulting from multi-party commissioning occurs in the construction contract. The contractor hires a new team member, the test engineer.

The test engineer is responsible for planning, scheduling, and coordinating the contractor's commissioning activities. The test engineer's responsibilities include:

- Elaborating the test criteria written by the design team into detailed test procedures for execution by the various subcontractors' technicians.
- Assembling project documentation, including the commissioning plan and schedule, operations and maintenance manuals, and test procedures and sign-off sheets.
- Helping the general contractor schedule work completion in a rational manner to accommodate test performance.
- Certifying completion of prefunctional performance checks and balancing.
- Scheduling and witnessing the commissioning tests before inviting the commissioning agent to witness the final tests, and then conducts the final tests.

In the multi-party approach, each party performs commissioning functions for which they are uniquely well-suited. An independent commissioning agent provides the quality assurance function at each stage of the process to assure the owner of success at the end of commissioning.

❖ Chapter 3
Design Requirements

Building commissioning requires considerably more information than traditionally has been presented in construction contract documents. The traditional philosophy has been that the contractor does not have to know the design intent or the design considerations in order to construct the building. All the contractor has to do is follow the drawings and comply with the specifications.

Upon completion of construction, as-built drawings and operations and maintenance manuals are turned over to the owner. The owner soon discovers these documents may be fine for maintenance but not for operating the building, particularly at operational extremes or when operational problems develop.

Most of the information required to effectively operate a building is developed during the design process. Unfortunately, that information usually is either buried in the design files or is still in the head of the design engineer. In either case, it is essentially lost to the owner's operations staff. The design requirements placed upon the design consultants must be changed to assure the owner receives all of the data and documentation critical to effectively operate the facility.

Traditionally, architectural and engineering (A/E) agreements have been fairly generic regarding design and document requirements. The building commissioning process requires these agreements to be much more specific about what the A/E is expected to provide upon completion of each design phase. In order to maintain flexibility, some institutions have a standardized A/E agreement that refers to attachments, making it easy to tailor to specific project requirements. The attachments are used to specify detailed documentation required. An example of such an attachment is included as Appendix 3-1. The A/E agreement specifies basic services and the attachment indicates requirements to be met at the conclusion of various phases of design: schematic phase, design development phase, and the construction documents phase.

To achieve the desired results, the owner must prepare a document that clearly defines the expectations for the A/E team. If the institution has a facilities design manual that it provides to consultants, then all of the requirements should be covered in that publication. If there is no such manual, then a "commissioning" document should be prepared and given to the design team by the owner's project manager. Excerpts from a university facilities design information (FDI) manual are included in later chapters and appendices, which collectively comprise the essence of a document specific to commissioning expectations and requirements. These documents can be modified to suit specific conditions and methods of doing business for any campus.

Several of these requirements are recognized to be "extra services." One of the many generic categories in the attachment is commissioning. In this case, commissioning is considered to be an extra service for which the design team is entitled to an additional, negotiated fee. In addition to an attachment, an institution may use sections of its FDI manual to provide more detailed instructions to consultants. The A/E agreement can reference the manual to make it a part of the contract with the A/E. Detailed information on design "deliverables," indicating the owner's expectations regarding consultants and contractors during the course of commissioning the project, can be provided in this manner.

Deliverables are specifically required at various stages in the design process. Many of these deliverables are not universally understood or accepted by consultants, so elaboration and negotiation is necessary. In particular, it is important to determine when a commissioning agent will become involved with the project and the extent of involvement to be required. An owner with minimal design experience and staff resources should involve a commissioning agent very early in the design process. In many cases, that person will be the only effective direct representative of the owner's operations and maintenance staff. In any event, the "extra services" agreement with the A/E team must clearly indicate direct expectations of the A/E team and the role of the commissioning agent in the process (even though the commissioning agent is hired directly by the owner).

Design Phases

Most owners are accustomed to the following basic design phases: programming, schematic, design development, construction documents, and bidding. Programming develops a detailed statement of owner requirements. The schematic phase translates written requirements into a conceptual facility design. Design development clarifies interpretations and presents an organized facility that will meet the owner's requirements that the design team will execute. Construction documents provide all details necessary for a contractor to build the facility. Bidding commits a contractor to construct the facility for a specific price by a specified completion date.

Two of these phases, the end of the design development phase and the end of the construction documents phase, are major plateaus—major documentation points—for the commissioning process.

The owner and design team must maintain a "commissioning mentality" throughout all design phases. One should always be thinking about how the systems will be successfully placed into operation, what special things may be required to do so, and how the operations staff will manage operations thereafter. Safety must also be a top priority. Equipment and components must be safely and conveniently accessible, with provisions for fall protection and the like, in order for the operations and maintenance staff to perform their duties. Lack of such consideration will inevitably negatively affect maintenance and operations and the ultimate effective operation of the facility.

Programming Phase

The owner should prepare a project program to establish design goals and constraints prior to engaging the design team. This program will most likely influence the consultant selection process.

The program should have two parts: a functional program prepared in conjunction with the client (the future tenants of the facility) that clearly indicates the intended use of the facility, the type and number of spaces required and the environment and utilities required in each space, and a technical program prepared by representatives of the operations staff who know what kinds of utilities and services will be required to implement the functional program.

This is the ideal time to briefly discuss the owner's expectations regarding commissioning: Does the owner plan to engage a commissioning agent? If so, during the design process or only during the construction process? Will the contractor be expected to engage a test engineer and perform a major share of the commissioning functions? These questions stimulate thoughts for later refinement during design. Answers are heavily dependent upon the type and complexity of the facility being planned and the quality and ability of the consultants and contractors likely to be involved with the project. If the owner lacks the technical resources to develop the program, often a consultant is engaged to do this step.

Predesign Conference

It is very important to have the project manager organize a predesign conference with the design team. That conference must include appropriate representatives from the owner's staff, who will be responsible for review of the contract documents, construction oversight, start-up and commissioning, and operations and maintenance.

The predesign conference should discuss a range of design and operations philosophies that are important for the A/E team to understand. Designers will be better able to design a building that will work for the institution when they understand the capabilities and limitations of the maintenance and operations organization. The discussion regarding commissioning is also important because most design consultants do not clearly understand commissioning.

The type of facility being developed tends to dictate relative need and requirements accordingly. Complex science facilities require the maximum commissioning effort; however, even relatively simple office or classroom facilities should have some level of formal commissioning beyond the usual testing, adjusting, and balancing work. Another important factor in determining the appropriate level of commissioning is the quality and reliability of the construction community. And, lastly, there is the ability of the owner's operations staff to work with the contractors to uncover and resolve any problems with the systems and optimize design-intended performance.

Regardless of the level of formal commissioning to be performed, the requirements for the contract documents should not change, since all of the resulting information is critical to the successful operation of the facility by the owner's staff. Accordingly, the following discussion indicates requirements that are important to the owner under any circumstance, many of which have not previously been provided to the owner by the design team.

Schematic Phase

In the past, mechanical and electrical subconsultants often were not included in the schematic or design development phases, except perhaps superficially. Common practice was to wait as long as possible before starting this work. Today, many decisions must be made at the outset that will directly affect the design of the mechanical and electrical systems. Therefore, these subconsultants must be actively involved in the design process from the beginning. Appendix 3-1 lists the requirements for the three design phases.

Commissioning discussions need to begin at this early stage. The more the consultants must think about how to get the building running right, the better the design is likely to be. The schematic design phase should produce a summary of the scope for the commissioning program and the appropriate outline specification elements. This is also the time for the owner to begin to seriously consider engaging a commissioning agent.

The commissioning deliverables at the end of the schematic phase are

1. A scope statement for the commissioning program, and
2. The commissioning outline specification.

Design Development Phase

The design development phase is the most important phase of the entire design process. All design criteria and operational parameters must be thoroughly considered by the consultants and the owner during the design development phase and final agreements documented at the end of that phase. All philosophical design issues should be fully resolved by the end of this phase.

The following table lists various design criteria and assumptions that must be considered, resolved, and documented during the design development phase.

General Construction

- Occupancy, usage, and schedule assumptions, all seasons,
- Building envelope assumptions,
- Floor load assumptions and calculations,
- Vibration assumptions and calculations,
- Noise criteria and acoustic assumptions and calculations,
- Fire and life safety considerations,
- Fire zoning rationale,
- Life safety operation modes and sequences.

Mechanical

- Indoor and outdoor design conditions, all seasons,
- Indoor "heat to" temperatures, general and specific,
- Indoor "cool to" temperatures, general and specific,
- Indoor humidity, general and specific,
- Air quality criteria,
- Air distribution criteria,
- Air distribution zoning rationale,
- Ventilation requirements and calculations,
- Heating and cooling load calculations,
- Energy conservation intentions and calculations,
- Occupied and unoccupied operating modes, all seasons,
- Life safety operating modes,
- For individual systems, sequences of operation, setpoints, and dead-bands,
- For interactive systems, sequences of operations,
- Equipment sizing criteria and calculations.

Electrical

- Lighting requirements and calculations,
- Fire and life safety considerations,
- Fire alarm zoning rationale,
- Equipment load assumptions and calculations,
- Energy conservation intentions and calculations,
- Occupied and unoccupied operating modes, all seasons,
- Life safety operating modes,
- For interactive systems, sequences of operations,
- Equipment sizing criteria and calculations.

The commissioning deliverables at the end of the design development phase are

1. Documentation of design criteria that shall occur after the consultants and owner have completely agreed upon all system operating philosophies. Documentation shall include one-line diagrams depicting operations at various design conditions, including fluid flow rates, temperatures, and pressures as necessary to comprehend the intended operation.
2. Functional and technical programs, amendments thereto, design criteria assumptions, design intent, and so forth, in an appropriately bound document, for retention by the owner and use by others as future alterations and revisions are imposed upon the original facility.

Construction Documents Phase

By this point, the major decisions have been made, agreed to, and documented. Now the consultants are expected to complete the design. The commissioning deliverables at the end of the construction documents phase are

1. Include in the construction documents all one-line diagrams and sequence of operations discussions necessary to fully identify how all systems are intended to operate during all design conditions. (It is important that all of this be included on the drawings—*not* in the specifications—for convenient use by owner's operations personnel.)
2. Specify contractor participation requirements for equipment and system testing before and during commissioning.
3. Specify prime contractor responsibilities during commissioning regarding coordination of prime and subcontractor responsibilities in cooperation with the commissioning agent engaged by the owner.
4. Specify contractor requirements for the operations and maintenance (O&M) manual, the definition of substantial completion and functional completion, and requirements for final acceptance.

5. Specify contract requirements for training of operations and maintenance staff, both on site and at special schools, as necessary.
6. Publish all amendments to the functional and technical programs, design criteria, and design intent that have evolved during the construction document phase and include them in the documentation published at the end of the design development phase.

Traditionally, owners have not imposed on consultants a particular arrangement for contract documents. It is important, however, that documents pertaining to system design and operation be arranged for the benefit of the owner's operations staff. Arranging these items on consecutive sheets, rather than randomly interspersing them throughout the documents will greatly aid the operations staff and will not significantly affect the work of the design team.

Consistent arrangement within the contract documents and records drawings is also desirable for a variety of reasons: plan review, contractor convenience, vendor convenience, and (most importantly) for the benefit of the maintenance and operations staff who must operate the facilities for many decades to follow.

Of greatest importance to the operations staff are mechanical and electrical one-line diagrams for the many systems within the facilities, related sequence of operations discussions, equipment schedules indicating design requirements, and final operational setpoints after testing, adjusting, and balancing and commissioning have been completed. Grouping these documents on consecutive sheets makes all of this information readily accessible.

The Commissioning Agent's Role During Design

The commissioning agent can provide valuable input to the design team on the owner's behalf during the design phase. From a design perspective, a seasoned commissioning agent will have first-hand experience regarding the pros and cons of most systems being designed. Most commissioning agents look at designs from the perspective of how well systems can be operated and maintained over their lifetime.

The commissioning agent should request that all design criteria be properly documented as this information will be necessary to develop functional test procedures. This documentation will be reviewed with the design team and owner so the owner knows the design limitations at the beginning of the project rather than discovering them during the commissioning process. This understanding can allow the owner to make budget decisions with better knowledge of consequences.

The commissioning agent will typically stress simplicity in design. This can help prevent over-design and guard the owner against purchasing additional sophistication that is unnecessary and unlikely to be used by operations staff.

The commissioning agent's review of design drawings and construction documents before bidding will provide valuable feedback as to how clear the documents are and how well they will be interpreted by contractors and vendors. This review can identify areas which, if not modified prior to the bid, may result in additional clarification and change orders after the project is underway.

Allowing the commissioning agent to participate in the value engineering process can help keep the process from becoming strictly a cost-cutting exercise. Eliminating such items as balancing valves and as-built drawings during value engineering is inappropriate because they have a significant operating impact after the owner takes over operation of the building.

Probably the most valuable service provided by the commissioning agent during design is ensuring that the design team properly develops the construction contract documents. If the contract documents are not exceptionally clear on all aspects of prime and subcontractor responsibilities, the commissioning program likely will not be performed as intended.

One final area requires emphasis: most design teams need assistance to ensure that commissioning and design are thoroughly coordinated throughout the contract documents. Oftentimes a great amount of equipment is specified in Divisions 2 through 14 that is not mentioned in Division 15 (Mechanical) or Division 16 (Electrical). Appendix 3-2 indicates thirty or so sections from Divisions 2 through 14 that contain equipment and systems that should be reviewed and considered for commissioning, which in turn must be coordinated with the mechanical and electrical work.

One of the most frequent (and serious) oversights is special purpose rooms such as clean rooms, cold storage rooms, and controlled environment rooms. Often the specific division specifications refer to building automation system (BAS) interfaces, but such requirements may be completely absent in BAS sections elsewhere. Consequently, these requirements are not included in the BAS vendor's work. These deficiencies are discovered later, after problems develop, when it is most costly to correct in terms of dollars and inconvenience.

These are areas where an experienced, independent commissioning agent can be most effective during design reviews. Since commissioning agents experience these kinds of problems routinely in the course of the commissioning process, they specifically look for these kinds of oversights during design review, and they are uniquely alert to coordination problems of this kind.

Summary

In commissioning, the owner participates extensively in the design process, particularly in operations considerations. In some institutional environments this level of participation may be difficult to achieve. If direct owner involvement is not possible or feasible, a commissioning agent should be engaged in these early phases to ensure that operational issues receive proper attention by the design team and that contract documents are properly structured to include commissioning.

❖ Chapter 4
Contract Document Requirements

Proper development of the contract documents is the key to an effective building commissioning program. This chapter describes contract document requirements for the three contracts usually involved with building design, construction, and commissioning.

Contract documents specify who does what, when, and how. Every function must be assigned. Each party must have clearly defined lines of communication. Each party must have clearly defined authority, with limitations explicitly stated.

Regardless of whether you choose single-party or multiparty commissioning, certain basic functions are common to both. The allocation of responsibilities will vary depending on which approach is used, but all of the commissioning functions discussed here still need to be included in somebody's scope of work.

The basic functions that need to be covered include:

- Develop project program,

- Prepare design document,
- Prepare project documentation,
- Define the scope of commissioning,
- Prepare the commissioning plan and schedule,
- Ensure construction in accordance with the project documents,
- Perform precommissioning checks and functional performance tests,
- Train staff,
- Correct deficiencies and retest, and
- Perform postoccupancy adjustments.

These functions must be covered in the responsibilities of one of the participants in the project: design consultant, contractor, commissioning agent, or owner.

The Three Contracts

Multi-party commissioning requires three contracts: the owner-architect agreement, the owner-commissioning agent agreement, and the construction contract. The scope of work, the lines of communication, and the lines of authority established in the construction contract and in the agreements with the architect and the commissioning agent must be carefully coordinated.

The owner-architect agreement sets the stage for the others. The design team (architect and engineers) plays a central role in the commissioning process. They document the design intent and basis of design, and define the contractor's commissioning responsibilities in the bid documents.

Next is the agreement between the owner and the commissioning agent. This contract must be carefully written in order to reduce the cost of commissioning while still making the expertise of the commissioning specialist available at critical points in the process to ensure optimum results. Key features of the commissioning agreement include provisions relating to conflict of interest, the scope of commissioning services, lines of communication, and authority.

The construction contract documents make up the third group. Bid documents regulate the commissioning-related activities of the contractor, the player with the greatest commissioning responsibility. Whereas agreements with the architect and commissioning agent are negotiated, the construction contract typically is competitively bid. The contractor's commissioning responsibilities must be carefully defined to ensure that all bidders are well-informed of the scope of the project and enable them to submit consistent bids.

It is essential to coordinate the scope of commissioning activities between all three contracts. Failure to coordinate will result in budget breaking requests for extra services and change orders, costly duplication of functions, or incomplete commissioning. It essential to ensure that all necessary commissioning activities are assigned to one of the four parties.

Owner-Architect Agreement

The owner-architect agreement must be tailored to include commissioning-related services from the design team. These modifications are primarily expansions of the design phase requirements, most of which are not yet included in the American Institute of Architects (AIA) Standard Form of Agreement. Since some of the deliverables are not universally understood by consultants, they must be defined. This can conveniently be handled by preparing an attachment to the architect agreement.

The scope of work described in the agreement should include design team assistance in developing the scope of commissioning services and the team's participation in selecting a commissioning agent. Engaging the team in the selection helps create a sense of "ownership" of the commissioning program and fosters good working relations with the selected commissioning agent.

The agreement should also address communication with the commissioning agent during design and construction. Construction phase activities of the design team should include review of commissioning-related submittals, though primary responsibility for such review belongs with the commissioning agent.

The design team must participate in resolving problems and conflicts during construction. The architect must retain final authority during construction, as is current practice. However, agreement scope should require that these parties follow the recommendations of the commissioning agent on commissioning related issues.

All parties must clearly understand that the architect (prime consultant) bears prime responsibility for full development of the commissioning program and all related contract document requirements. Since most of the commissioning activity involves the mechanical and electrical work, most of the work to develop the commissioning specifications will fall to the mechanical and electrical subconsultants. Nonetheless, it is imperative that the architect retain overall responsibility.

Owner-Commissioning Agent Agreement

The owner negotiates an agreement for commissioning services directly with the selected commissioning firm. This contract should incorporate provisions relating to conflict of interest, the scope of commissioning services, lines of communication, and authority.

The owner must have the full allegiance of the commissioning agent during the project. The commissioning agreement, therefore, prohibits the commissioning agent from having any business affiliation with, financial interest in, or contract with the design consultants, subconsultants, contractor, subcontractors, or suppliers for the duration of the agreement. Violation of such prohibitions constitutes a conflict of interest and is cause for the owner to terminate the agreement.

The scope of services includes responsibilities during the design, construction, and postoccupancy periods. In the design process, the commissioning agent should review each design submittal for commissioning-related qualities. These qualities include consistency of design with design criteria, maintainability, serviceability, and physical provisions for testing. The services provided should also include commissioning specifications, with emphasis on identifying systems to be tested, associated test criteria, and acceptable results.

The commissioning agent participates in on-board review sessions and other design meetings with the design consultants to ensure the commissioning agent is as familiar with the design as feasible. The agent's participation allows them to understand the design and to be a more effective reviewer. Commissioning agent participation in the design process pays off in increased effectiveness during the construction and postoccupancy phases of the project.

During construction, the commissioning agent performs a quality assurance role relative to the contractor's commissioning activities. In this role, the agent reviews the qualifications of the contractor's selected test engineer, commissioning submittals, , O&M manuals, training plans equipment submittals, and shop drawings related to systems to be commissioned. Commissioning submittals include the commissioning plan and schedule, static and component test procedures, and systems functional performance test procedures.

The commissioning agent's duties also include witnessing and verifying the results of air and hydronic balancing, static tests, component tests, and systems functional performance tests. To the extent the owner's staff is involved in witnessing the testing, adjusting, and balancing, and equipment testing, the commissioning agent's role can be reduced to witnessing critical functional performance tests and a sample of other functional tests. The owner's staff benefits from witnessing as much of the balancing and functional performance testing as possible. The commissioning agent's function, then, is to ensure that test technicians properly understand and execute functional performance test procedures.

The commissioning agent's contract should also include analyzing the functional performance test results, reviewing the contractor's proposed corrective measures when test results are not acceptable, and recommending alternate or additional corrective measures as appropriate.

The contract should also indicate clear lines of communication and authority. These should be tailored to the owner's level of involvement in the project. If the owner is intimately involved in all aspects of design and construction, then the owner should manage the commissioning agent's involvement. During construction, the commissioning agent should communicate formally with the contractor only through the established lines of communication, that is, directly through the architect, or indirectly through the architect via the owner.

In any case, it is essential that the owner be kept informed of decisions.

In cases where the owner is only marginally involved in the day-to-day business of the project, it may be desirable to allow the commissioning agent to communicate with the architect directly on commissioning issues. This is recommended only when the owner is very confident of the expertise and judgment of the selected commissioning agent, and only when the commissioning agent and architect have a good relationship.

The authority of the commissioning agent should be limited to recommending improvements to the design or operation of the systems, solutions to problems encountered, and acceptance or rejection of test results. The commissioning agent should not directly order the contractor to make changes. Only the architect may make changes in the design or order construction changes. It is essential that the owner speak to the contractor with only one voice.

Construction Contract

The construction specifications define the scope of the contractor's participation in commissioning. Since most consultants are not well-versed on the overall requirements for a comprehensive and thorough commissioning program, it will be useful to share with them the sample documents provided in the appendices.

Appendices 4-1 through 4-13 are excerpts from University of Washington construction projects and the university's facilities design instruction manual. These documents are provided as examples; they must be tailored to suit requirements and conditions relative to each institution and the way it conducts business. A brief summary of recommended specifications sections follows.

Section 01650—Facility Startup/Commissioning

Two versions of Section 01650 are included in the appendices. Appendix 4-1L presents Section 01650 for large projects, which includes specific requirements for the prime contractor to include the services of a test engineer to coordinate all commissioning requirements for the contractor and subcontractors. Appendix 4-1S presents Section 01650 for small projects, which includes commissioning requirements for the prime contractor but does not require the prime contractor to engage a test engineer. In either case, the section clearly indicates the prime contractor is responsible for the overall commissioning program specified in the construction contract.

In the case of Section 01650 for large contracts, the section lists the minimum qualification requirements for the test engineer and identifies the scope of the test engineer's responsibilities. The contractor must submit the qualifications of the proposed test engineer for approval by the architect and owner.

Experience has demonstrated that the overall cost for commissioning will be less if the contractors are required to perform virtually all of the startup and performance testing activities. Further, if contractors know in advance that they will be required to make everything operate per the design intent, they will likely improve the overall quality of the installation and workmanship.

Section 15995—Facility Startup/Commissioning

Similar to Section 01650, there are two versions of Section 15995 included in the appendices. Appendix 4-2L presents Section 15995 for large projects and Appendix 4-2S presents Section 15995 for small projects. In either case, the section clearly indicates the role and responsibilities of the mechanical subcontractors and vendors regarding their participation in the commissioning program. Section 15995 refers to Section 01650 and Division 17, indicating Division 15 responsibilities relative thereto.

Section 16995—Facility Startup/Commissioning

Similar to Section 01650, there are two versions of Section 16995 included in the appendices. Appendix 4-3L presents Section 16995 for large projects and Appendix 4-3S presents Section 16995 for small projects. In either case, the section clearly indicates the role and responsibilities of the electrical subcontractors and vendors regarding their participation in the commissioning program. Section 16995 refers to Section 01650 and Division 17, indicating Division 16 responsibilities relative thereto.

The Division 15 and 16 subcontractors provide input to the commissioning plan, assist in elaboration of test criteria into test instructions, provide O&M manual materials, provide qualified personnel for equipment startup and training, provide qualified technicians to perform component tests and functional performance tests, operate systems during testing, adjusting, and balancing, and functional performance testing, correct deficiencies promptly, and (may) participate in off-season testing. Similar provisions may be appropriate in other divisions of the specification (e.g., lab equipment, elevators).

Division 17—Commissioning

It is recommended that Division 17 be dedicated to deal specifically with the scope and details of the commissioning program. Division 17 is the heart of the commissioning specification. (Commissioning could be covered in Division 18 if Division 17 is already dedicated to controls.) Via a series of subsections, Division 17 details test engineer responsibilities, identifies which systems are to be tested, and lists in detail system configurations to be tested, the functions to be tested, test criteria, and acceptable test results. Appendix 4-4 provides a sample Table of Contents.

All Division 17 sections included in appendices are intended to be examples that would be tailored to suit a specific design and included in the construction contract documents. Some sections are unique to certain types of buildings, e.g., science buildings. In all cases, there is only one version of each section—not one for large projects and another for small projects, as note for previous sections. Every section would be revised to suit the specific project and specific commissioning approach adopted for the project.

Section 17100—Commissioning: General Requirements

This is the introductory section to Division 17 and would be uniformly included in every contract. An example is included as Appendix 4-5. This should be carefully reviewed since it includes requirements which often are included in the General sections of the contract documents. It is likely that conflicts will result if the two areas are not properly coordinated.

Section 17100 describes the test engineer's functions in detail. This would be modified to refer to prime contractor functions (deleting reference to a test engineer) in the case of small projects, wherein the services of a test engineer may not be required. In either case, the tasks included are

1. Update, with any changes made during construction, the basis of design document, system operating descriptions, and one-line diagrams.
2. Review software documentation.
3. Provide input to the construction schedule.
4. Coordinate work completion and functional performance tests.
5. Write functional performance test procedures.
6. Assemble O&M manuals.
7. Verify installation.
8. Perform pre-startup checks.
9. Supervise system start-up.
10. Supervise TAB (if required under Division 17).
11. Supervise and witness functional performance tests.
12. Present owner staff training.
13. Assemble record drawings.

Section 17 Subsections—Commissioning Specific Systems

Appendix 4-4 provides a sample table of contents for a comprehensive scope of systems commissioning. Each section would contain detailed requirements for the different systems.

The long and detailed examples are actual excerpts from a University of Washington project, prepared by UW engineering staff in association with the design team. They are included here to emphasize the level of detail commissioning requires. Many of the documents might seem redundant; however, they are vital to a successful project. Commissioning is a process; one which must be followed step by step, from system to system and component to component. There are no shortcuts. The reward is a building that works.

Not only must the design team tailor each section to suit the project, but the Acceptance Procedures paragraph in each section also must be carefully thought through and completed by the design consultants. The design consultants must develop the functional performance test (FPT) criteria under this paragraph. Each feature or function to be verified as a condition of acceptance of the subject system must be incorporated. The consultant lists the various conditions under which the system is to be tested, along with the acceptable results and allowable deviation for each test.

The subconsultant responsible for design of each particular system, in collaboration with the owner's commissioning agent, writes the functional performance test criteria. These are not test instructions or protocols. Section 17100 requires the contractor's test engineer to expand the functional performance test criteria into test procedures; step-by-step instructions to field technicians on how to perform each test. These test instructions cannot be written in advance during the design phase because most tests are specific to the actual equipment provided, which is not known until after the contractor's submittals have been approved.

The criteria for acceptance must be written to allow objective determination of whether the test results are acceptable or not. Rather than requiring simply that a temperature sensor be "accurate," the criteria should specify a range of acceptable performance compared with some accepted standard.

For example, Section 17590—Commissioning: Environmental Control Systems, might require that an outside air sensor be calibrated against an instrument of known accuracy. It would require that tests be performed at 32° F and 100° F air temperatures. (Specify that testing may be completed when ambient air temperatures are within 5° F of the specified temperatures. Or require the contractor to provide artificial means of subjecting the sensor and calibration instrument to the specified temperatures.) Results must show agreement between the sensor and the calibration instrument within tolerances specified for the sensor in the controls section of the specification. Test criteria written in this way do not require testing personnel and witnesses to come to some arbitrary agreement on the meaning of the word "accurate."

A word of caution: Criteria must be consistent with the specified equipment. For example, most commercial temperature sensors are not accurate to a 0.01° F tolerance, so specifying accuracy to that degree is inconsistent with reality and not required by the service intended.

Section 17595—Commissioning: Testing, Adjusting, and Balancing.

Prior to commissioning, the University of Washington chose to contract directly for testing, adjusting, and balancing as a quality assurance procedure for all construction projects. Now, for large projects where a commissioning agent will be engaged to provide quality assurance, the university includes this section in the contract documents as a responsibility for the contractor. Coordination of TAB work on large projects is often very difficult. Therefore, it is to the owner's benefit to have the prime contractor manage this activity.

For most UW projects (those less than $10 million), this same specification, with minor modifications, is used to hire a TAB firm which reports directly to the owner. This is another "quality control" measure since, via the TAB contractor, a great deal can be discovered about what has not been properly constructed and installed and what does not seem to operate as intended. In both cases, a percentage of final reported readings are required to be repeated in the presence of the commissioning agent or owner's staff to verify consistency between the actual and reported readings.

The reader is encouraged to browse through the appendix specifications for an indication of the type of functional performance test criteria required. The specifications are not complete; they do not address all systems. The UW is building a library of test criteria for designers to use on future projects. Each subsequent project will, in turn, provide additional test criteria to the library. In the long term, the objective is to maintain a comprehensive library for reference which will considerably reduce the amount of work required by consultants for each project and develop a high level of consistency among projects.

Section 00800—Supplementary Conditions and Section 01700—Project Closeout

These two areas are intentionally presented out of sequential order. This has been done in order to first acquaint the reader with the requirements placed on the contractor to ensure an effective commissioning program. It should be evident that there is an impact on scheduling and performance. In order to further assure timely execution and completion, additions to these sections are appropriate.

It is customary to include a subsection of Section 00800 titled Time of Completion and Liquidated Damages. Customarily this section refers to substantial completion and final acceptance and requirements related thereto. *Substantial completion* has become a legally recognized point in time which allows the owner to take occupancy of the facility even though there is work yet to be completed and documentary, regulatory, and contractual closeout requirements are yet to be met. Substantial completion usually requires the owner to take operational control of the facility and, because of that, all warranties commence on that date also. Further, liquidated damages associated with time of completion traditionally end at this point. However, the contractor may continue to be in the facility for several weeks or months finishing the project.

Often, this point is reached before testing, adjusting, and balancing and commissioning have been completed. The owner should be concerned about the loss of time of completion and liquidated damages while significant requirements still remain to be completed. Commissioning is a significant requirement which must not be lost at this point. All too often, many contractual requirements tend to be overlooked, waived, or otherwise sacrificed in a rush to allow the contractor to "finish" the project and be paid retainage, etc. Often there are negotiated resolutions to construction events and difficulties which add pressure to closing out the project.

In order to guard against this eventuality, the owner may adopt another liquidated damages milestone, *functional completion*. This is a defined point in calendar days after substantial completion wherein all remaining TAB and commissioning responsibilities of the contractor must be completed, with another (reduced) liquidated damages amount included. This process helps to ensure the contractor completes all responsibilities of this critical requirement. Contract document language states that all commissioning requirements, except functional performance testing, must be met prior to substantial completion. Functional performance testing, including the completion of associated final documents and reports, may be completed after substantial completion and prior to functional completion.

The following are excerpts from a University of Washington project:

> **00805 Time of Completion and Liquidated Damages**
> *The work shall be commenced on the effective date specified in the Notice to Proceed and shall be substantially complete within a period not to exceed 592 calendar days (or approximately nineteen and one-half months). For failure to achieve Substantial Completion of the Work within the time provided, Contractor shall pay Owner $2,500 for each calendar day from the date when Substantial Completion should have been achieved to the date Substantial Completion is actually achieved.*
>
> *Functional Completion shall not exceed 60 calendar days following Substantial Completion. For failure to achieve Functional Completion of the Work within the time provided, Contractor shall pay Owner $500 for each calendar day from the date when Functional Completion should have been achieved to the date Functional Completion is actually achieved.*
>
> *Final Completion shall be 90 calendar days following Substantial Completion. The provisions of General Conditions Section 3.07, for liquidated damages, remain in effect.*

The project closeout requirements of Section 01700 include subsections which more thoroughly define substantial completion. The university also includes, in the appropriate paragraph:

> *Complete all commissioning requirements in Division 17 except "Functional Performance Testing."*

And then add:

> *1.10 Functional Completion*

> *A. Contractor shall submit acceptance procedures test check-off sheets, signed by the commissioning agent and accompanied by the commissioning agent's final report recommending Functional Completion.*

Each project varies depending on the formatting each prime consultant has adopted for their office. One must integrate the foregoing requirements as appropriate for each project.

Summary

The consultant agreement requires the architect and subconsultants to produce commissioning specifications, to coordinate the actions of the commissioning agent with the construction process, and to participate in resolution of problems encountered during commissioning.

The commissioning agent agreement includes review and consultation during design, review of shop drawings, review of product and commissioning submittals, test verification, and problem resolution during design.

The contractor bears the bulk of the commissioning burden, as specified in the construction contract. The general contractor schedules and coordinates construction and commissioning activities. A test engineer hired by the prime contractor schedules the contractor's various commissioning activities and coordinates them with other construction activities, assembles project documentation, writes functional performance test procedures, and directs correction of deficiencies. Subcontractors perform commissioning tests and make corrections.

Regardless of the form of commissioning selected, the basic commissioning functions must be included in one or another of the contracts. Coordinate the construction contract and the agreements with the architect and the commissioning agent with regard to scope, lines of communication, and authority.

❖ Chapter 5
The Commissioning Process

The commissioning process will vary from project to project. Based on what systems are to be commissioned, the commissioning agent can develop a proposal for services that will ensure an effective commissioning process. The requirements of an effective commissioning program are consistent regardless of project size and complexity. The following are typical services to be provided.

Typical Responsibilities in the Commissioning Process*
(CA = commissioning agent, TE = test engineer)

1. TE and CA review design criteria and construction documents.
2. TE develops a commissioning plan; CA reviews and approves it.
3. TE develops testing, adjusting, and balancing schedule; CA reviews and approves it.
4. TE develops commissioning schedule; CA reviews and approves it.
5. TE and CA review control strategy and software.

6. TE develops system functional performance test procedures; CA reviews and approves them.
7. TE and CA perform on-site construction inspection.
8. TE develops training program for owner's operations staff; CA reviews and approves; TE performs training with CA's assistance.
9. TE performs testing, adjusting, and balancing; CA observes and approves TAB.
10. TE performs commissioning using the functional performance test procedures; CA observes and approves.
11. TE performs final job documentation and close out; CA reviews and approves.

**Note: This list represents an "ideal" process for large projects that warrant both a test engineer for the contractor and a commissioning agent for the owner. Smaller projects may only require equivalent activities by the prime contractor, rather than a test engineer. Some owners will opt to utilize appropriately trained staff to perform the commissioning agent functions. No matter what the variations may be, the contractor and owner participation/responsibilities remain as indicated.*

Commissioning Step-by-Step

Review Of Design Criteria And Construction Documents

The CA and TE must review the projects' design criteria and construction documents in order to know the basis for system functional test procedures. During this review, the CA should bring to the attention of the owner any items that might be considered questionable. The primary purpose of this review, however, is for the CA and TE to understand the intent of the design and the criteria.

Examples of design criteria are 1) a minimum flow rate of 5 feet per second in the piping of a pure water system, 2) a 0.05 inches of water pressure differential between spaces in a clean room environment, 3) an outside dry bulb and wet bulb design temperature, etc.

The CA and TE review construction documents to become acquainted with how the systems are to layout in the building, how the mechanical and electrical systems are to operate in conjunction with one another, and quality standards the installed equipment must meet.

The TE must have a good working knowledge of all the aforementioned information before functional test procedures can be written and the tests performed.

The Commissioning Plan

The TE prepares the commissioning plan to provide an informational document that outlines the responsibilities of the design team, contractor, commissioning agent, and owner during the commissioning process. This plan identifies the systems to be commissioned and the documentation processes to be used. The plan shall also include the testing, adjusting, and balancing schedule and the commissioning schedule.

Develop Testing, Adjusting, And Balancing Schedule

The TE is responsible for developing the TAB schedule. To do so, the TE must determine whether the construction schedule is realistic and understand well the timing of completion of construction. After reviewing the construction schedule, the TAB schedule should be developed and integrated into the construction schedule. It is important for the schedule to be reviewed and updated on a weekly basis with the contractors, construction manager, and owner.

Ideally, adequate time should be provided for the TAB work before commissioning and occupation by the owner. Often, construction completion is delayed, while the occupation date is not. The CA must keep the owner aware of construction delays and how they will impact the TAB and commissioning.

Develop Commissioning Schedule

Once the TAB schedule has been finalized, the TE develops the commissioning schedule. This schedule will be based on the construction completion schedule and the TAB schedule.

Air and hydronic systems should be commissioned after they are balanced. If occupation of certain spaces is critical, the schedule should indicate that these spaces are to be commissioned prior to those not as critical. Once the schedule is developed it should be given to the contractors, construction manager, CA, design team, and owner for review and comment. After this review the schedule should be finalized.

The schedule should be reviewed with the contractors, construction manager, CA, design team, and owner on a weekly basis. Based on this review, the schedule will be updated weekly. As commissioning progresses, construction omissions and design problems may be identified that will need to be corrected before commissioning can continue. As with testing, adjusting, and balancing, it is imperative that the CA keep the owner aware of any problems that may have an adverse effect on the commissioning schedule and subsequent occupancy by the owner.

Review Of Control Strategy And Control Software

The CA and TE should review the control strategy prior to developing the functional test procedures. This includes review of the control contractor's submittals and allows the CA and TE to identify how the contractor intends to meet the design criteria. It allows the CA to see what type of controls, the number of controls, and how they will sequence with each other to control the systems. Since the TE is writing test procedures for these systems, he or she must know its component parts prior to writing the tests.

Prior to performing the commissioning of systems using direct digital control (DDC), the CA needs to have adequate time to review the control systems software. This review is twofold. One purpose is to acquaint the CA and TE with the idiosyncrasies of the software being used, and the second is to assure the control strategy will meet the design intent and the owner's requirements.

Development Of System Functional Test Procedures

Development of functional test procedures is crucial to the proper performance of the commissioning process. In order to develop these procedures the TE must have reviewed the design criteria, construction documents, and the approved temperature control and building automation control systems. Based on this information, written test procedures and test record sheets will be prepared by the TE. Each procedure should be explicit and exact enough so it can be easily repeated at a later date, by a different tester, in the exact same manner as originally done. The procedures include the design criteria.

After the tests have been developed, they should be reviewed by the CA, design team, contractors, and owner. The review by the design team serves to ensure that the TE and CA have correctly interpreted the intent of the design. The review by the owner serves to ensure that the design intent will meet their needs as an operating entity. The review by the contractors allows them to know how their installation is to be tested. After all parties have reviewed the tests, the TE will modify them as required, obtain the approval of the CA, and issue the final tests.

On-Site Construction Inspection

The CA and TE have a relatively minor involvement in the construction process. The primary responsibility of performing construction inspection should remain with the project managers and design team. They should ensure the contractor is adhering to the design criteria and quality of workmanship, and is staying on schedule. The CA and TE serve as a second set of eyes to the design team and project manager. They should be aware of how and where systems are going in so that the TE can dovetail the TAB and commissioning functions into the project schedule so all work can be completed before owner occupancy.

Basic CA service includes periodic site visits and scheduling of owner's staff participation in the commissioning activity. During this time the CA will relay any supplemental observations of construction activities to either the construction manager, design team, and/or owner for their attention and remedy, if necessary. Detailed punch lists, enforcement of the contractor work schedule, or other actions required to complete the job prior to TAB and commissioning may be necessary to meet the owner's occupancy date.

The CA's site inspections primarily focus on ensuring the systems being installed are accessible and lend themselves to be tested, commissioned, and maintained once the job is complete. Often, general contractors will indicate the work is done when, in fact, power is not connected, or the controls that make it function are not ready. False starts create delays and frustration.

It is the CA's responsibility to inform the owner whether the contractor is meeting the schedule. Often, the contractor and CA will disagree on how well the contractor is meeting the schedule. Although this can place the CA in an uncomfortable position, it is the CA's responsibility to give the owner an honest and unbiased analysis of the situation.

Develop Owner's Operations Staff Training Program

In order for the TE to have a strong understanding of the training requirements most appropriate for the owner's operations personnel, he or she should have ample opportunity to review the design intent, arrange the comprehensive schedules for TAB and the system functional performance tests, become familiar with subcontractor and vendor personnel, and prepare the system functional performance test procedures. It is at this point, before system functional performance tests are conducted, that the TE should develop the training plan. This is appropriate because some of the training will likely be in a classroom setting, covering operations philosophy, and the rest of the training will be in the field in conjunction with performing the system functional performance tests. It is important for operations personnel to be trained in the philosophy of the design and operation before participating in the tests so that they may better understand the intended results.

Classroom training should be conducted in a setting suitable for lecture, display of training materials, and discussion with trainees. Instructors must be selected based on their ability to provide effective training and be technically qualified to effectively discuss the equipment and systems being discussed. Training aids must be directly representative of the installation being discussed. Ideally, as much of the training as possible should be videotaped for follow-up review and for use in training new employees over the years. Effective handout materials will also be valuable for operations staff.

Perform Testing, Adjusting, And Balancing

Prior to beginning the testing, adjusting, and balancing, the TE should develop the balancing logs, schematic one-line diagrams of the systems to be balanced, and balancing agendas for each system. These should be prepared and presented to the CA for review prior to commencement of the balancing.

During the CA's on-site construction inspections, the CA looks for such items as missing balancing dampers, improper sensor location, inaccessible VAV boxes, and any other items that would impede balancing. Deficiencies should have been documented and transmitted to the owner. Prior to commencing the TAB, a final pass should be made to ensure systems are ready for balancing. The TE should have completed all related start-up procedures approved by the CA. TAB should then begin and follow the TAB schedule. If there are items that adversely affected the balance, the CA should immediately advise the owner so problems can be resolved and TAB completed.

Once TAB is complete, a rough draft of the final report should be prepared by the TE. After the commissioning is complete, any rebalancing that was required for the commissioning should be incorporated in the report and the final report submitted to the CA for approval.

Perform Commissioning Using The Functional Test Procedures

The actual commissioning of the systems should be performed by the TE in association with technicians from appropriate subcontractors. The CA should observe final functional performance tests in association with technicians from the owner's operations staff.

To eliminate possible wasted time in trying to commission systems that are not ready for commissioning, the following process is suggested. When the contractor has completed installation of a system or piece of equipment (to be commissioned) per the design documents and the work is complete and functional, the TE should perform commissioning in accordance with the approved procedures and work out all discrepancies prior to requesting CA review and approval. Upon completion of successful system functional performance tests (FPT), the TE should notify the owner in writing through proper formal communication channels that the systems are ready for review and approval by the CA. The owner's operations personnel and the CA should observe the final FPTs.

During final system functional performance testing, the TE should fill out the functional test record sheets for approval by the CA and the owner's records. If the systems fail due to a correctable contractor error or design error, the contractors and/or design team should implement appropriate corrections. Upon completion, systems should be retested. The rough functional test record sheets and a rough final report should also be prepared.

Final Job Documentation And Close Out

Once the commissioning is complete, a final report should be prepared by the TE that includes the final functional test record sheets and list of any major unresolved discrepancies. This report should be reviewed with the CA prior to completion of the final document.

Fine-Tuning The Commissioning Plan

The success of a building commissioning program is determined to a great extent by the level of discipline required to follow all steps in the process. In order for commissioning to work, the greatest caution must be taken to avoid being coerced into skipping or only partially completing steps in the commissioning process.

First, it is easy for prime contractors to claim that all of the commissioning requirements will just add to the difficulty of getting the project finished, slow the project down, and be the reason why the project cannot be finished on time. That simply does not have to be true. Knowledgeable contractors admit that commissioning induces a level of discipline in the construction schedule that often will not occur otherwise. The prime contractor does have to spend what appears to be an inordinate amount of time integrating commissioning into the construction schedule. This is difficult because many prime contractors and subcontractors have not had experience with the intricacies of functional performance testing.

Often, contractors don't allow enough time for testing and don't coordinate their work to allow testing to start at the earliest possible time—all of which good planning, scheduling, and coordination can achieve. Knowledgeable contractors appreciate having the commissioning requirements clearly defined so that they can be accounted for during bidding and properly integrated into the construction schedule.

During construction of one building, the subcontractor did not complete the check-off sheets, but told all parties that pretesting had been completed. The commissioning agent and owner assembled to formally witness the tests. In the first day-and-a-half, over 134 failures were discovered.

Further, even the most well planned construction projects tend to fall behind schedule. As the schedule gap widens, pressure mounts for the contractor to strive harder to minimize the slippage. It is tempting at this point to make up time by unilaterally skipping or proposing to skip a range of tests—particularly those that require repeating the same test on a number of identical or similar items. This is an easy trap to get into, but it must be avoided; or, at worst, very judiciously allowed. Those who are applying the pressure should be clearly advised of the potential consequences of bypassing various tests. The ultimate penalty falls to the owner when dysfunctional components are discovered that seriously impact the owner's programs.

In Chapter 1, discovery was offered as a synonym for commissioning. Another term that should be strongly associated with commissioning is *discipline*. Perhaps the most important factor in an effective commissioning program is establishing strict discipline for completing all testing requirements as planned, no matter how trivial some may seem when pressures mount to save time. The additional time is well spent.

During construction of one UW building, the subcontractor did not complete the check-off sheets, but told all parties that pretesting had been completed. The commissioning agent and owner assembled to formally witness the tests. In the first day-and-a-half, over 134 failures were discovered. As a result, the work was rejected, further testing was halted, and the subcontractor was sent back to complete the pretesting and check-off sheets as originally required. The discipline requested and required was not followed and the contractor paid the price.

One of the most burdensome areas for this discipline is point-to-point testing, usually associated with building environmental control and automation systems. It is often viewed as unnecessary drudgery. Installation subcontractors will say that all inaccuracies will be discovered in the normal course of control check-out and TAB. Whereas it is easy to be lulled into believing this, experience has proven otherwise time and again. Further, point-to-point testing must be completed prior to requiring the TAB firm to begin balancing, since fully operational controls are critical to setup, balancing air distribution, and testing air terminal box operation. Lack of appropriate verification of point-to-point control will inevitably prevent the TAB firm from completing its work as planned and on schedule.

Another important discipline is the development and maintenance of testing records (logs) to track the overwhelming series of tests, simple and complex, successful and failed. It is not possible to keep track of all of this activity in one's memory; therefore, it is imperative that testing logs be developed. Appendices 5-1 through 5-3 are examples of testing logs and follow-up check-off sheets used at the University of Washington to keep track of progress. These procedures continue to be refined as each new commissioning project occurs. They are provided here as a model to assist in getting started.

❖ Chapter 6
Selecting the Commissioning Agent

By now you should have a fairly good understanding of the role of the commissioning agent. The commissioning agent is a major partner in the overall process of design and construction; therefore, selection of a fully qualified commissioning agent is critical to the success of the process.

What are the qualifications to be a commissioning agent? Before answering that question it is appropriate to make sure that the term *commissioning agent* is properly understood. A commissioning agent is a commissioning firm. The commissioning process requires a firm because it encompasses so many areas of expertise that it is unlikely one individual would have all the skills necessary. Once the firm has been engaged by the owner, then the firm's designated commissioning project manager is thereafter referred to as the commissioning agent.

Criteria

The first step is to decide what activities the commissioning agent is expected to participate in. This decision should be based in part on whether the owner's staff is qualified to review design documents at various review stages and to evaluate progress during construction. It is also determined in part by the amount of money the owner can allocate to the commissioning process.

If funding is extremely limited, the environmental control system is the highest priority for commissioning. So doing will lead to discovery of other components that may not be operating correctly, even though the environmental control system is.

If the owner has experienced staff capable of effectively reviewing the design as it progresses, then it may not be necessary to engage the commissioning agent until construction begins. However, the latest practical time to engage the commissioning agent is shortly after the construction contract has been awarded so that the commissioning agent can be involved with review of schedules, submittals, and testing programs to be developed by the contractor.

The criteria for a good commissioning agent is heavily weighted toward extensive field experience with installing and testing mechanical and electrical equipment and systems. High in the experience priorities is experience with testing and commissioning environmental control systems. In fact, if funding is extremely limited, the environmental control system is one system that should be commissioned above all others. So doing will lead to discovery of other components that may not be operating correctly, even though the environmental control system is operating properly.

Request For Qualifications

Once the scope of the commissioning program has been developed, the owner can determine what kind of skills and experience will be required to carry it out. That leads to the development of a request for qualifications (RFQ) to be placed as an advertisement in the appropriate local or regional media; e.g., a daily journal of commerce, newspaper, or trade journal. Advertising in national publications should be avoided because a local or regional firm is preferable if available and qualified.

It is important for the RFQ to clearly indicate the minimum qualifications that are acceptable for the project. At this stage in the development of commercial/institutional building commissioning, there are few truly qualified firms, but there are a vast number of "wannabes." It is important to ensure that the project is not awarded to an inexperienced firm. Commissioning requires a knowledgeable, tested firm. A well written RFQ will discourage firms that do not have the necessary experience from applying.

Appendix 6-1 is a copy of an advertisement used by the University of Washington to solicit submissions of qualifications from commissioning firms.

The advertisment should identify the nature—research facility, computer lab, and so forth—of the construction project to be commissioned and the types of systems to be commissioned. This gives respondents a sense of the skills and experience required to commission the building.

In addition, the following specific items should be required from respondents:

1. History of the company.
2. Commissioning expertise and capability.
3. Local experience during the past three years on projects of similar size and type.
4. Resumés of personnel to be assigned to the project, with project responsibilities.
5. Special attention to on-site project manager.
6. References.

Further, the advertisement should state that finalists to be interviewed will be required to present comprehensive evidence of prior project commissioning schedules, test procedures, system functional performance test procedures, and final documentation of all tests. This will discourage many firms from applying because they will not be able to meet the interview requirements.

Selection Process

At the same time that the RFQ is prepared, one should also prepare a selection evaluation form. This evaluation form can be used both in the original screening of submittals and during the interviews of the finalists. In order to be objective, it is best to develop this evaluation form before submittals are received. Appendix 6-2 is a sample evaluation form.

There are several important considerations that warrant specific comment.

1. The Request for Qualifications does not ask for cost proposals. The commissioning contract should be negotiated with the selected firm, at which point the scope of work and the contract cost will be finalized.
2. Identify the firm's experience in the commissioning field. Specifically, it is important to know of successful commissioning projects of similar complexity and sophistication.
3. The firm must identify who will be the on-site project manager in charge of the commissioning program. Experience has shown that the person assigned to lead the project (in the field, in this case) is the key to the success or failure of the work to be done. The proposed project manager's background and references should be provided for evaluation.
4. The firm should also indicate anyone else who will be involved, on what aspects of the project, and prior relevant experience.

One must be cautious about what is purported to be commissioning experience. Some testing, adjusting, and balancing firms will suggest they do commissioning. TAB work is not commissioning. Commissioning includes TAB work, but goes beyond what the average TAB firm is experienced at doing.

Consulting engineering firms will likely apply, claiming they do final inspections, punchout buildings, do start-up and, therefore, do commissioning. Although most design firms follow their projects completely through the construction process to acceptance, not many have experienced, full-time, field commissioning engineers on staff

Finally, one last critical issue must be restated: the consulting firms or contractors already associated with the project should not be considered for commissioning agent. The commissioning process is a major quality control element of the project. As mentioned previously, these groups may not be capable of objectivity, particularly if problems pertaining to their own work are uncovered. Therefore, it is best if the commissioning agent is an independent, third-party participant who has no emotional or economic tie to the project (other than the commissioning fee).

Interviews

The interview process is very important. One should learn a great deal about each firm's commissioning experience and the different perspectives represented by the firms. One can also get a sense of the firm's culture, which can be important in relation to the project, consultants, and contractors associated with it. The owner must appreciate the sensitive position of the commissioning agent in regard to the other participants. The commissioning agent must be complementary to the project and be accepted appropriately by all other participants. Of course, the ground has been laid for this participation in the contract specifications.

It is recommended that all finalists be invited to interviews on the same day. This helps ensure that all owner's participants will be available for all interviews, and that important points are not forgotten over a period of several days. The entire process can be completed in one day, including discussion with the interview team and selection of the preferred firm.

Selection of the interview team is important. Since few institutions have completely similar capital improvement program management structures, it is difficult to make precise suggestions. However, a general philosophy suggests the team members include the owner's project manager, a representative for the maintenance and operations division, and a representative of the client (end user).

The client should participate for two reasons. First, it is difficult to explain to the client all that commissioning entails and its importance to the success of the project. By participating in the interview process, the client gains considerable knowledge. Second, it is important for the client to be confident that the best selection was made. The same philosophy would apply in regard to the maintenance and operations representative.

Whether to invite the design team (at least the prime consultant) to participate will differ from project to project.

Negotiation—Scope And Cost

The owner has already identified the preferred scope for the commissioning program. Often, the owner realizes the program is comprehensive and optimistic in regard to cost and available funds. The selected commissioning agent is then asked to prepare a commissioning program proposal using the owner's program outline as the basis for the proposal. The proposal should be prepared with costs clearly itemized so that the merit of various components of the program can be discussed and weighed against the respective costs. Ideally, the entire building, including all systems, should be commissioned. However, available funding may dictate a curtailed scope involving only the most critical systems. These are the final decisions to be made and, of course, they can be altered later on by amending the firm's agreement as conditions may warrant.

❖ Chapter 7
The Costs of Commissioning

The immediate concern of all owners is the cost of the building commissioning program. The additional cost of commissioning might be considered to be substantial. But to put costs in perspective, one must examine the benefits of building commissioning. Though the variety of approaches and relatively recent introduction of building commissioning to the commercial/institutional construction industry make good cost and benefit data scarce, some general conclusions are available to help in budgeting.

The benefits of commissioning lie in avoiding the costs of not commissioning. Building commissioning costs between 2 and 4 percent of the mechanical system construction cost, plus 1 to 2 percent of the electrical system construction cost. Factors affecting the magnitude of the cost and benefit figures include the use and complexity of the systems involved and the method of commissioning.

Benefits

Avoiding The Costs Of Not Commissioning

By understanding the costs of not commissioning, one can gain a measure of the benefits of commissioning. The costs of not commissioning are the expenses owners incur to correct design and construction deficiencies in order to make new or renovated facilities work as they are intended. Owners manage to work out most of the problems in new facilities, even without formal building commissioning, but do so at substantial cost. The costs of not commissioning include staff time to correct the problems, additional equipment or materials, lost time and productivity of the occupants, health and safety impacts, excess energy costs, impacts on central plant utilities, legal fees, and the intangible "hassle factor."

British Columbia Buildings Corporation Study

At the 1993 National Building Commissioning Conference in Sacramento, California, a British Columbia Buildings Corporation (BCBC) representative cited estimates of the costs of not commissioning mechanical systems from a study done in 1989. The study drew information from five BCBC buildings that were described as "not problem buildings," but which were not commissioned. Mechanical construction costs averaged $10 per square foot.

The study attributes to building commissioning a $0.05 per square foot improvement in operations, a 5 to 10 percent reduction in energy consumption, and a cost of 0.75 percent of the original mechanical construction cost to make corrections after the fact. They concluded the operation and maintenance costs of not commissioning ranged between $0.45 and $0.75 per square foot for the first three years of operation. So the cost of not commissioning these five buildings during the first three years amounted to 4.5 to 7.5 percent of the mechanical costs.

The presenter went on to estimate the costs to occupants of not commissioning. His argument is similar to the argument used to estimate the impact of poor indoor air quality. Occupant dissatisfaction with environmental conditions in their work spaces results in decreased productivity. "At an annual payroll cost of only $200 per square foot of occupied space, if every fifth employee spent 30 minutes of work time per month on such activities (gripe sessions, letters of complaint, meetings, investigations, etc.) the resulting cost would be $0.13 per square foot per year." Using the same payroll costs, increased absenteeism (every fifth employee takes an extra two days off per year) may cost an additional $0.33 per square foot per year. Over three years, these lost productivity figures may total as much as $1.38 per square foot, 13.8 percent of the original mechanical contract.

When the occupant impacts are added to the operations and maintenance costs, the total is $2.43 per square foot, or 24.3 percent of the mechanical construction cost. Although these are difficult figures to confirm, even if the real costs are only one quarter of the estimates, they still show the substantial magnitude of the costs of not commissioning.

In addition to the preceding there are also significant intangible costs involved in not commissioning. What does one say when the dean or a department chair calls, exasperated with the endless series of failures in a new facility they have helped fund? How does one explain the departure of a leading faculty member who can no longer tolerate the interruptions to their research resulting from building systems failures? How does one counteract the bad press that results from lingering indoor air quality complaints in a new building?

Commissioning Approaches Compared

When considering the costs of commissioning, keep in mind that the commissioning approach selected has an impact on the costs. One should look at the relative costs and associated trade-offs of several methods of accomplishing building commissioning. The potential for delays resulting from commissioning and the potential for conflict of interest are factors that should be weighed along with costs. The following are five commissioning scenarios, which will be discussed in turn:

- All commissioning functions performed by an independent third party—***independent commissioning agent.***
- All commissioning functions performed by the design team—***designer as commissioning agent.***
- All commissioning functions performed by the contractor—***contractor as commissioning agent.***
- All commissioning functions performed by the owner—***owner as commissioning agent.***
- Commissioning functions split between an independent commissioning agent, the design team, the contractor, and the owner—***multi-party commissioning.***

Independent Commissioning Agent

The most accurate guide for estimating the costs of commissioning using an independent commissioning agent is to approach cost as a function of the construction cost of the commissioned systems. Since the costs of systems are related to both their extent and their complexity, the construction costs are a good indicator of the commissioning costs.

The cost of using an independent commissioning agent for the mechanical systems is about 2 to 3 percent of the mechanical construction costs. Commissioning electrical systems costs 1 to 2 percent of the electrical construction contract amount. Costs of commissioning other systems, such as elevators or laboratory equipment, are likely to be similar to electrical system commissioning costs. Mechanical systems cost more to commission because they have more dynamic functions to commission than other systems.

Duplication of effort and negotiated (instead of competitively bid) commissioning service agreements make the independent commissioning agent the highest cost approach. However, this is also the method with the lowest potential for conflict of interest. The independent commissioning agent has no stake in defending the design or the construction and is therefore free to bring all issues affecting commissioning and successful building operation to the owner's attention.

The downside of the independent commissioning agent is the potential for delay. Due to the need to keep the site activities of the commissioning agent and the contractor from interfering with each other, much of the commissioning testing that will discover problems will not occur until after the contractor has completed installation and has demobilized. Corrections take longer when subcontractors are called back after they have left the site. Meanwhile, the facility cannot be used as intended. Such delays seem inevitable when testing uncovers deficiencies after the contractor has departed.

Designer as Commissioning Agent

The designer-as-commissioning agent approach may cost less than employing an independent commissioning agent. The anticipated cost saving accrues from the familiarity of the design team with the design; they won't need to spend time learning how the systems are intended to work.

However, there are two factors that make this a less desirable option. As with the independent commissioning agent, the designer-as-commissioning-agent approach suffers the same high potential for delays, and for the same reasons. The most critical issue, however, is the potential for conflict of interest. Remember that the commissioning agent must subject the design to the same scrutiny as the construction. Because of their role in the project, designers are not in a good position for this task. Designers are often less expensive commissioning agents simply because they are less likely to be objective in their evaluation of the design.

Contractor as Commissioning Agent

A third possible approach is charging the contractor with the responsibility to perform all commissioning agent functions. The contractor-as-commissioning agent approach minimizes project delays by integrating commissioning tasks into the construction schedule. Commissioning costs are among the lowest when the contractor is the commissioning agent because the costs are determined in a competitive bid environment. Unfortunately, a low bid does not always result in high quality.

A contractor acting as a commissioning agent is subject to the same high potential for conflict of interest as would a designer. For the contractor, the obvious conflict is that correction of construction problems is an added cost to the contractor. Those costs cut into the contractor's profit margin. Further, in a bid project, the contractor is not available to perform commissioning tasks during design, making this option inappropriate for bid work. The contractor-as-commissioning agent option appears desirable at first glance due to the low cost and low potential for delay. But, there is little difference between this method and the status quo, and therefore it is not recommended.

Owner as Commissioning Agent

If the owner has sufficiently sophisticated staff, the fourth option—performing all commissioning services with owner's staff—may be the lowest cost option. There are no markups on the staff's time. Also, staff retain all the expertise gained during commissioning, and there is no potential for conflict of interest. Indeed, no one takes greater interest in assuring the systems are properly designed, operational, and maintainable than the people who will operate and maintain them. Most owners, however, lack the staff to provide their own commissioning services. This method may also suffer project delays for the same reason as the independent commissioning agent and the designer-as-commissioning agent options.

Multi-Party Commissioning

The last approach to be considered is the multi-party approach. The combination of participants and tasks we have developed for multi-party commissioning is intended to utilize the strengths of each participant while keeping costs low and minimizing delays and conflicts of interest. Each participant is responsible for the commissioning functions they are best qualified to perform.

The design team and the commissioning agent work together during design to establish the scope of commissioning and to specify the tests to be performed. The commissioning agent also provides review of the design.

The contractor (via the test engineer) coordinates, schedules, and performs commissioning testing, assembles documentation, and conducts training. The commissioning agent is there to verify the results of tests and help identify solutions as needed, but construction corrections and delays are the contractor's responsibility.

When contractors begin to understand the benefits they reap from multi-party building commissioning, their bids will reflect the difference. Commissioning produces cost savings for the contractor due to several factors: improved on-site efficiency, fewer deficiencies to resolve at substantial completion, and fewer hidden deficiencies.

The contractor's on-site efficiency improves because the commissioning process refines the scheduling of subcontractors' work. Previously, the prime contractor had to deal with anxious subcontractors, each demanding priority for their work. The commissioning process imposes a logical flow to many aspects of the work, ensuring that requisites for each subsequent stage of work are scheduled in a timely fashion.

The contractor's costs decrease due to a reduction of the extent of the deficiencies list at substantial completion. Subcontractors tend to be more careful in the completion of their work when they know a process is in place to discover deficiencies. Of the deficiencies that do remain, more are discovered during commissioning, while subcontractors are still on site.

The contractor's costs decrease due to a reduction of the number of deficiencies discovered after the contractor has left the site. Deficiencies that would have remained hidden until after the contractor had left will instead be corrected prior to substantial completion.

It can be seen that contractor cost savings may well exceed the additional costs incurred to participate in commissioning. Unfortunately, in the short term, owners are likely to see higher bids as contractors bid the commissioning work conservatively, with ample margins of safety built in. As the relative magnitude of the contractor's costs and benefits associated with commissioning become better understood by contractors, their bids will reflect the cost benefit.

In this scenario, the independent commissioning agent can be replaced by the owner's staff, if such expertise is available in-house. In addition to the other advantages of multi-party commissioning, if the owner serves as the commissioning agent, the owner retains the systems expertise gained during commissioning. In the long run, a multi-party approach, with the owner performing the tasks of the commissioning agent, is the optimum approach to building commissioning.

The Costs of Commissioning

British Columbia Building Corporation Estimates

At the 1993 National Building Conference discussed earlier, a British Columbia Building Corporation representative cited the following mechanical systems commissioning cost estimates. These figures are based on an approach in which an independent commissioning agent, the designers, and the contractor share responsibility for mechanical systems commissioning. In many respects the BCBC approach to building commissioning is similar to the multi-party commissioning method.

Based on a mechanical construction cost of $10 per square foot, the study estimates the following range of per square foot costs:

$0.025 to $0.010 extra designer time

$0.100 to $0.300 contractor (commissioning agent)

$0.025 to $0.200 owner (operations staff)

Comparison of commissioning methods.

Commissioning Method	Cost	Conflict	Delay
Designer as commissioning agent	High	High	High
Contractor as commissioning agent	Lowest	Highest	Lowest
Independent commissioning agent	Lowest	Lowest	High
Owner as commissioning agent	Lowest	Lowest	High

These costs total $0.15 to $0.60, which is 1.5 to 6 percent of the mechanical construction costs. This compares with the study's previously cited estimates placing the costs of not commissioning at 4.5 to 10.5 percent of the mechanical construction costs, not including occupant impacts.

The merits of the five methods of performing commissioning are summarized in the table, Comparison of commissioning methods.

The optimum approach in most cases is multi-party commissioning because: 1) costs are reasonable, 2) the potential for conflict of interest is low, and 3) the risk of project delay is low. Multi-party commissioning is at its best if the owner can perform the duties of the commissioning agent in order to retain the expertise gained in the commissioning process.

❖ Conclusion

The costs of *not* commissioning far exceed the costs of commissioning. Commissioning costs are best estimated based on the construction costs of the commissioned systems; 2 to 3 percent of mechanical construction costs and 1 to 2 percent of other systems costs. The cost of commissioning depends on the commissioning approach used. Multi-party commissioning offers an optimal mix of low cost, low potential for conflict of interest, and low potential for project delay.

There are significant intangible costs involved in not commissioning. Can anyone afford the embarrassment and political costs of not commissioning new facilities? Can anyone afford to embarrass a dean or a department chair with an endless series of failures in a new facility that they have helped to fund? Can anyone afford to lose a leading faculty member because he or she can no longer tolerate the interruptions to their research resulting from building systems failures? Can anyone afford the bad press that results from lingering indoor air quality complaints in a new building?

By not commissioning new facilities we risk creating situations that call into question the stewardship of facilities administrators. Ensuring that new facilities work as they were intended is a requirement of responsible facilities administration. Building commissioning is the key to delivering facilities that function as intended and fully meet the client's needs.

❖ Building Commissioning in Practice: A Case Study

Phoebe Caner, P.E.
Commissioning Engineer
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The Physics/Astronomy Building In Context

In 1992, the University of Washington was in the midst of planning four new laboratory buildings, to be constructed over a two-year time period. Problems that had arisen in earlier, uncommissioned projects had already demonstrated the high costs of not commissioning similar buildings. In light of these earlier experiences, the university's engineering services division was able to obtain university support to create a commissioning program to enhance the quality and operability of the new facilities. The commissioning program they put in place has introduced substantial changes to management of construction on the University of Washington campus.

The University of Washington was given a grant by a local utility to cover the salary for a new commissioning engineer on the engineering services staff. As part of the work covered by BPA funding, the university staff commissioning engineer will generate four case histories, of which this is the first. This case study addresses the commissioning of the Physics/Astronomy building—a 256,000 square foot, $45 million project completed in 1994. The scope of commissioning was restricted to the building automation system.

This case history will explore the following questions:

- What are the costs and benefits of commissioning?
- How does commissioning affect energy consumption?
- How can commissioning be performed most effectively?
- How can design and construction management be altered so that problems are uncovered and solved early in the project?

Because building commissioning is a relatively new field, and because the costs and benefits depend in turn on the methods used, this report focuses primarily on how commissioning can be managed to maximize its cost effectiveness. Specific sections of this case study discuss the following:

- The Physics/Astronomy Building in the context of University of Washington's commissioning program,
- How on-site testing was conducted and lessons learned in the process,
- Estimates of energy savings for specific test findings,
- The types of problems that were most effectively addressed through commissioning.

Perspective on the role of commissioning in quality control, by examining a system that wasn't commissioned; the relationship between project management and commissioning; and commissioning's role in restructuring the marketplace to support pragmatism.

Goals

Experience at the University of Washington indicates that traditional design and construction practices reflect inadequate attention to and understanding of building operations and maintenance. As a result, buildings tend to offer poor access to mechanical equipment, drawings, and O&M manuals, and less than desirable levels of repairability, durability, and performance under non-design operating conditions.[1]

With the introduction of commissioning, the university has shifted some of the problem solving which traditionally took place after occupancy into earlier phases of the project to reduce expenses and inconvenience to the occupant. In order to accomplish this transition, the university commissioning program has adopted the following specific goals:

- Increase the level of operational expertise applied to design and submittal review and preoccupancy testing.
- Enhance construction contract enforcement by providing test data on critical component, system, and intersystem HVAC performance.
- Help project managers sort out design, manufacturing and installation problems quickly at a time when the responsible parties are still readily available to correct errors.
- Improve building operator training and access to as-built drawings and O& M manuals.

Scope

Commissioning has expanded the amount of witness testing at project completion, by increasing the number of prefunctional tests witnessed by operations shop staff, and introducing an independent commissioning agent to write, witness and report findings for functional performance tests (FPTs).

The focus of commissioning at the University of Washington thus far has been on the HVAC system—particularly the building automation system (BAS), and the interface between HVAC, BASs, and fire alarm and emergency power systems. This scope of work was selected partly because the high rate of innovation[2] in HVAC has made it difficult to ensure quality through traditional oversight by manufacturers, designers, and contractors. Other parts of the building—such as high voltage electrical systems and structural concrete—receive third-party inspections and testing under standard construction contracts, and are not, therefore, considered under commissioning. The term *commissioning* is used in this report to describe the new activities which have arisen at the University of Washington under that name, but it is recognized that the term could be more broadly applied to include aspects of traditional construction practice simultaneously being pursued on the campus.

Schedules And Contracts

Because the Physics/Astronomy project was under way when the commissioning program came to fruition, commissioning was added after the construction contract documents had been finalized. In later projects, the presence of commissioning in the construction contract documents has grown so that the costs for contractor participation can be part of the base budget, and each party's role in commissioning can be established early in the project.

Commissioning activities entered the Physics/Astronomy project schedule as follows.

4/89	*A/E Selection*
7/91	*Contract Documents*
11/91–4/94	*Construction*
1/94	*Commissioning Contract for Commissioning Agent*
1/94–3/94	*Point-to-Point Testing of BAS System by Contractor and UW Control Shop*
2/94–6/94	*Testing, Adjusting, and Balancing (additional TAB activities later)*
5/94	*Substantial Completion*
7/94–10/95	*Project Warranty Period*
7/5/94–8/5/94	*Functional Performance Tests with Commissioning Agent Oversight (first set)*
7/5/94–8/19/94	*Move-in*

8/26/94	*Final TAB Report for the Air Systems*
9/12/94	*Building Opens*
9/23/94	*FPT Final Summary Report Received*
7/95	*Functional Performance Tests (second set)*

Steps yet to be completed:

Final TAB Report for the Hydronic Systems

AEI Presentation to Operations Staff

The commissioning firm executed a second round of tests about a year after the first to determine the performance of corrections to problems encountered during the first round of tests. As the final phase of their work, the firm will summarize their findings in a presentation to the university's building operations staff.

Commissioning By And For The University Operations Staff

Use of Operations Staff in Commissioning

Allocation of operations staff time to capital projects has simultaneously improved the quality of new construction and increased the ability of the operations staff to take over new buildings when construction is completed.

A critical step in the early development of the campus commissioning program was the promotion of an experienced technician from the control shop to full-time support for engineering staff involved in commissioning. The individual selected to fill the Operations Support for Engineering (OSE) position combines strong verbal skills, dilligence, enthusiasm, and practical understanding of what makes control systems work. This person also has more than thirty-two years of experience in communications, electronics, and control systems. The OSE reviews design documents and control submittals, works with the control contractor to reduce discrepancies between the programming and the sequence of operation prior to testing, and helps brainstorm solutions to problems left unsolved by the design.

In addition to the OSE's work, prefunctional testing is witnessed by those operations staff most expert in the types of systems being tested. Because the use of operations staff as owner-witnesses benefits both quality of construction and the ease of operation, there has been some debate within the university about whether funding for the shop's participation should come out of the capital projects or the operations and maintenance budget. In general, the capital projects budget covers the cost of O&M staff witness activities, but the O&M budget covers the time spent in training. In the case of Physics/Astronomy, the control shop staff was used extensively to witness the control system point-to-point tests, with funding out of the project's capital budget. Static duct and pipe testing, however, was witnessed by engineering and construction staff, whose salaries are not assigned to specific budgets, because the project budget was not sufficient to allow the use other staff.

Access to Training and Documentation

In the past, the operations and maintenance staff were not provided with the documentation and training needed to perform their jobs with the highest efficiency. One is told that buildings were turned over before the technicians being put in charge had even seen the inside of the building. O&M manuals and drawings were stored centrally, either in the shop buildings or in the university's record keeping system for the entire campus. Distribution of O&M manuals after project completion was time-consuming, and information was sometimes difficult to find. The introduction of commissioning has resolved much of this problem through

- Preoccupancy familiarity with the building.

Training is carefully orchestrated and shop staff become familiar with the building through participation in commissioning before taking over the building.

- An operations room in each new building.

In each of the new buildings, a well-secured room is assigned to the operations and maintenance staff. It contains the mechanical and electrical O&M manuals and drawings, the building automation system (BAS) manuals and a personal computer terminal.

As a result of commissioning, the capital budget for the Physics/Astronomy project included an attractive and fully functional operations room with a BAS control terminal, tables, and wall-mounted shelving. One member of the UW control shop noted that provision of documentation to the control room was timely, complete, and well organized: "It couldn't have been done better."[3]

On-Site Testing: The Process

Standard Test Strategies And Nomenclature

On-site tests typically proceed from the simple to the complex, moving from static component checkout, through static system evaluation, to dynamic system and intersystem tests.[4] The process can be categorized into three phases:

1. Prefunctional testing
2. Testing, adjusting, and balancing
3. Functional performance testing

Component and static tests are sometimes referred to as prefunctional tests. For a direct digital control system, these prefunctional tests can be called point-to-point (PTP) tests. Because the commissioning of the Physics/Astronomy project was restricted to the direct digital BAS, the only prefunctional test referenced in this report is the PTP.

During point-to-point testing, the controls contractor demonstrates to the owner that each point on the building automation system is hooked up, properly identified in the software, and wired without reversal (e.g., the damper closes rather than opens when the BAS indicates it is closed). The goal is to assure control system connections are correct and the actuated dampers and valves are working.

PTP is, in some cases, expanded to include other tests—for sensor calibration, full valve and damper closure, or spanning of valves and dampers—because the PTP may be the last time comprehensive testing is executed on the components that are most numerous (e.g., zone-level components).

As in any standard construction process, the testing, adjusting, and balancing (TAB) contractor adjusts and tests water and air distribution systems at maximum design capacities once the static tests have been completed. At the UW, TAB is contracted to the commissioning agent, the university, or the general contractor. At Physics/Astronomy, the TAB agent reported directly to the university.

The commissioning program then provides for a series of dynamic system and intersystem tests, called functional performance tests, executed by an independent commissioning agent hired directly under contract to the university. Functional Performance Tests (FPTs) are executed after completion of PTP tests and TAB, to examine system and intersystem performance under dynamic, automatic control through a wide range of conditions, including a variety of failure modes. This is in contrast with PTP, which is primarily component level testing, and TAB, which typically examines performance only under design (capacity) temperature and flow conditions.

Point-To-Point Tests

The Test Procedure

The point-to-point test procedure at the Physics/Astronomy building was developed by the control contractor and reviewed by the OSE and the staff mechanical engineer (ME). The first version submitted to the university appeared to have been written for another project, with inadequate revision. With the help of the OSE, the contractor ultimately produced a complete and specific test procedure.

Test Execution

Section 15900 of the construction contract specifications required the control contractor to execute PTP (and a large number of other) tests for UW control shop witnesses. PTP tests were initially performed per specification by the contractor, but the bulk of the testing was executed by the control shops without contractor contribution.[5]

A member of the UW control shop staff working on the project noted afterwards that it seemed as though UW personnel were being used by the control company to execute the first checkout of the system. The contractor's control technician asked a UW control technician, "Why should I test the system if you guys are going to?"

Frustration among the shop staff ran high, because the testing was tedious and much time was spent standing by while numerous problems uncovered during testing were corrected by the contractor. The UW labor cost $39,402, billed at roughly $43 per hour to the project.

Using Operations Staff Time Effectively

Fortunately, the university technicians involved in this first point-to-point checkout quickly developed an effective set of guidelines that has been successfully incorporated in two subsequent projects. This success demonstrates that the use of university operations staff as test witnesses can provide the mutual benefit to capital projects and operations that was originally envisioned. Those guidelines, outlined below, should be stated in the control specifications of the contractor's work, and reviewed in a meeting between the university staff mechanical engineer or project manager and all of the test participants before they begin their work.

- The university representative is not to execute tests except in the role of observer, noting, for example, damper response or reading a value at the terminal.[6] This limitation is not as severe as it might sound, since point-to-point typically involves 1) commanding a damper or valve, or placing an instruction at the terminal, and observing the response in the field, or 2) imposing a temperature change on a sensor and watching the result at the terminal.

- The contractor is not to fix problems while a university witness is observing tests (unless the correction only takes a few moments). If UW witnesses feel, based on the first few PTPs, that the control system is not ready for witness testing, they should notify the UW ME and, if appropriate, the PTP should be stopped until the system is first checked out more thoroughly by the contractor.

- If possible, PTP should be executed before the ceiling tiles are installed, to cut down on the costs of PTP. Otherwise it is more difficult to find and gain access to actuated valves and dampers in the ceiling plenum.

- The contractor shall complete an independent checkout of the system prior to witness testing, and shall sign off completion of such a test before witness testing begins.
- The shop is to be notified by fax at least 24 hours in advance of any testing.

The first of these ground rules was covered by the Physics/Astronomy construction contract, but it has been found that during construction it is essential to periodically review construction contract requirements with the participants to make sure the contract is being enforced where that is in the owner's best interest.

Communications: Getting Feedback

The operations and maintenance staff are most used to performing real work, not communicating about what they see in the field. If the customer's control technicians observe tests as part of their own training, they may prefer not to be responsible for creating observation reports. If, on the other hand, the control technician is being used as an owner witness for testing and is being paid out of capital project budgets, it is important that the engineering staff emphasize to them the importance of their observation reports in assuring efficient quality control, and to decide with them at the onset of point-to-point what should be reported and to whom. The following information is most helpful, and doesn't require much paper.

- Notification of any problems with the commissioning procedure (e.g., inadequate notification prior to test, contractor fixing equipment during test, unreasonable delays, etc.).
- A list of any discrepancies found during testing. A spreadsheet filled out by hand on the day of each test is helpful. It can provide a single line per discrepancy, giving the point ID, point location, problem description, witness initials, date observed, date retested, and initials of UW witness checkoff.

At Physics/Astronomy, the monotony of writing down the PTP test results on data sheets for every test whether or not any problems were identified became discouraging during the period that the UW control shop was performing the PTP tests. It has been found in subsequent projects, however, that writing up concise discrepancy lists is a task that the shop witness pursued with skill, timeliness, and satisfaction.

The operations staff should present their findings to the customer's engineering or construction management staff rather than directly to the contractor, so that the contractor doesn't become the sole keeper of the discrepancy lists. This also frees up the operations staff to note what they see without feeling pressure from the contractor to come to a specific conclusion.[7] It should be emphasized that the operations staff incur no personal liability through their written reports, that their observations of what was "seen," in addition to any conclusions drawn, will be helpful. Such descriptive notes can be placed on the back of the spreadsheet.

Functional Performance Tests

Finding an Agent; Development and Execution of Tests

The consulting firm selected for the Physics/Astronomy building has extensive experience in design and commissioning of complex projects. During the past few years they have designed several large laboratory research facilities. Their staff includes skilled trades people with in-depth, hands-on technical experience in construction management, start-up, testing, and debugging building equipment.

The commissioning contract included $65,000 for the commissioning agent's services and $44,957 for services to be provided to the commissioing agent by the control contractor in executing FPTs.[8] The scope of work included:

- Development of functional performance test procedures and a test schedule,
- Oversight of test execution by the contractors,
- FPT test reports,
- Coordination of communications with the university and mechanical design consultant to develop solutions to problems identified during testing.

The commissioning agent immediately began by familiarizing himself with the design documents, visiting the site, and creating a list of items that had to be completed prior to testing. Execution of the FPTs took roughly five weeks. During that time, the commissioning agent, a UW witness, and the control contractor's technician worked roughly sixty hours a week on the tests. Scheduling and coordination of tests were performed by the commissioning agent. Either the UW assigned staff mechanical engineer or the UW commissioning engineer observed most of the tests.

The agent produced weekly reports of the findings and a summary report at the end of testing. The FPT procedures themselves served as data collection sheets and were delivered to the university with the final report.

Communication between the FPT test team and the mechanical design consultant was maintained on almost a daily basis to clarify any questions that arose about the intent of the design, and to initiate changes to the design when testing indicated that was necessary. Changes were recommended by the agent and approved by the designer and university ME. The university ME would then write a memo to the university construction coordinator who would contact the contractor and arrange for a change order or new contract. Lists of deficiencies due to manufacturing or installation were transferred from the ME to the UW construction coordinator to the contractors. No commissioning meetings were held during FPTs.

The Characteristics of a Good Commissioning Agent

In many ways, the commissioning agent's work exemplified how commissioning can succeed. The agent demonstrated a thorough understanding of the contract documents, and kept a set of mechanical drawings and specifications in the control room to reference as questions arose during testing. The agent's strong knowledge of equipment start-up and testing, with an understanding of HVAC design, helped him to effectively interpret data as it was gathered.

One of the greatest challenges in any construction project is efficiently coordinating the work of a large number of people. In this case, participants were used efficiently. The university ME and the commissioning agent kept lines of communication open between the commissioning team, the mechanical design consultant (in California), the contractors, and the university's construction management group.

The commissioning agent also scheduled tests well. His discipline, energy, and organizational skills kept things moving effectively. The working hours were long and regular, as were the meeting places, so that all of the parties involved could easily be included without getting bogged down in phone calls to coordinate schedules.

Trend Logs

Trend logs were collected and printed out, at the university's request, during FPTs, but the data collected appears not to have been used. In future projects, it will be necessary to include a requirement to analyze the trend log data if the time taken to gather it is to be justified.[9]

Sensor Calibration

On-site testing and calibration of sensors was not addressed in detail either in the construction contract or the commissioning contract, resulting in a weak test procedure. Sensor calibration was only checked at a single point (e.g., single temperature), and calibration of water temperature sensors was sometimes checked by placement of a sensor on the surface of the pipe.

The calibration certification documentation requirements, and minimum accuracy levels, need to be specified for the test instruments. The calibration verification test procedure should be addressed in detail in a general front section to the FPT procedures.

Numerous Small Components

Sensors fall under the general category of numerous small components. Sensors are given special mention above because they are the components through which the rest of the HVAC system becomes visible and accountable to first the testing agents and then the customer. Other small numerous components raise the same challenges, however, in developing an effective commissioning strategy. What percentage should be tested? Who does the testing? What happens to untested items if a significant number of the tested sample fail? How much redundancy is expected between the contractor's checkout prior to witnessed tests; the prefunctional tests witnessed by the shops; and the FPTs?

Because of the potential amount of labor involved, and the potential ambiguity about extrapolation of test data from a small sample, zone level tests need to be considered carefully by the customer when developing the scope of commissioning, to make sure that 1) the customer has identified the reason for each test, 2) the test procedure is specified in enough detail that there is an understanding from the beginning about the minimum level of rigor required, and 3) the specifications address the contractor's obligations for responding to a specified rate of failure in a specified sample size.

Spare Instruments

During one day of testing, the lack of an accurate pressure gauge reduced the quality of tests executed and required rearranging the test schedule. It may be desirable to have back-up instrumentation available during testing to avoid such problems.

Efficient Test Reports

Although intense effort was invested in developing FPT procedures and then filling in the FPT procedure sheets as tests progressed, the university soon discovered that their extensive length made the FPT procedures less useful in following up on the FPT results than the timely, complete, and concise weekly summaries of the problems found during testing.

The format of commissioning reports is important because the bulk of data collected can be disabling to the reader. Separating the test procedures from the data sheets makes data presentation concise and easy to review. In describing a problem found in commissioning, the weekly summary reports should include the date of the observation, who observed it, what was observed, and the equipment ID (e.g., SF-1), and location (e.g., second floor mechanical room). Tentative conclusions about the cause and proposed solution may also be included, along with a description of any action taken at the time of testing to correct the problem.

For the final summary report, the university requested that problems be listed by equipment type so that the information could easily be transferred to the contractors. The summary report should include failure rates (number of items failed/total number of items), explaining any extrapolation based on test sampling sizes.

Reporting Findings Corrected During Testing

FPT reports should include descriptions of problems identified during FPT which were corrected during testing. Otherwise the owner will not know the impact of the commissioning investment, and the evolution of any recurrent or widespread problem will not be well understood.

Changes to software made during testing are particularly important to document, because they may be inadvertently lost through subsequent software "upgrades." University staff reminded the control contractor and commissioning agent periodically of the importance of documenting problems corrected during testing. Otherwise this activity would tend to be abandoned.

Tracking the Status of the Ever Changing Software

BAS programming typically does not remain unchanged for even a 24-hour period during the start-up of a new building. For that reason, it is important to document the status of the software at the time of testing to leave a record of what is being tested.

Fortunately, the programming used by the Physics/Astronomy control system is easy to read, and can be pulled up on the screen and printed at any time. During testing, we found that it was most efficient to review the test procedure before execution and ask the control contractor's technician whether or not the software was capable of the prescribed sequence-of-operation. When he knew that there was a software problem, we could avoid wasting time with a test procedure that might not reveal anything further.

Addressing Unforeseen Circumstances

As FPTs were executed, unexpected circumstances often required a change in the procedure. For example, the original test procedures involved extensive use of "virtual points." It turned out that the creation of virtual points resulted in loss of trend log data, so other methods, such as setpoint adjustment, were substituted.

The commissioning agent's strong knowledge of HVAC made it possible for changes to occur without adversely affecting the quality of testing, but it is important for the customers to realize that alterations are likely to occur. The university requested that changes be approved by the university witness, and that they be documented in the report.

Steps can also be taken to keep down the number of changes made to test procedures after they have been approved by the customer. First, the customer can make available to the commissioning agent copies of any change orders affecting the systems to be tested, so that commissioning test procedures reflect the current status of the design. Second, test procedures depend heavily on the specific characteristics of the BAS system being used. (How does the BAS handle global commands? Is there such a capability? Can the zone temperature setpoints be globally adjusted? How easy is it to set up a "virtual" point?) It is helpful, therefore, to have the control company meet with the commissioning agent before test procedures are written, or to review the test procedures before they are finalized. If test procedures are written before a control system is selected, another approach can be taken: place any characteristics critical to efficient testing into the BAS specifications (e.g., the BAS shall have the capacity of issuing global commands for adjusting zone setpoints).

Controlling the Progress of Tests

During FPTs, the control contractor's technician would sometimes begin improvising procedures or correcting problems without first consulting the commissioning agent. While this behavior is entirely natural and well intentioned, it is important to impress on the control contractor's technicians that only the prescribed procedures are to be executed during testing so that outcomes can be well understood. If, for example, the university is testing the ability of the BAS to automatically return to normal power after coming off emergency power, the value of the test may be completely negated if the control contractor is at the terminal clearing alarms during the test. If this is explained in advance, the control contractor is likely to avoid touching the controls.

Continuity Between Formal Testing and Post-Occupancy Operations Activities

While formal commissioning involves systematic and relatively comprehensive testing at the end of construction, debugging occurs after occupancy and focus on problems after they have become apparent (this is sometimes referred to in operations as "crisis management"). The ability to create continuity between the formal comprehensive testing of commissioning and the focused, crisis-driven debugging that occurs after occupancy increases the effectiveness of each. If the operations staff are well-informed about what was found during FPTs and keep an ongoing record of any subsequent related problems, correction of FPT discrepancies is likely to be more complete in that problems are less likely to be forgotten and faulty solutions less likely to persist without correction. If the operations staff is well-informed about the findings from the FPTs, they may be better able to diagnose problems that were not identified during testing.

On-Site Testing—A Sample Of Findings And Solutions

Commissioning the Physics/Astronomy building brought forward problems in design, manufacturing, and installation. Early resolution of these problems reduced energy consumption, labor costs, occupant discomfort, and potential occupant risk in the event of a fire. Three of the problems found during FPTs are described here, to provide the reader with a flavor of the work that was done. One notes for example:

- Serious control system malfunctions result from small oversights,
- Some problems are quickly solved once they have been identified, while other solutions take a long time,

- Lessons are learned through commissionining that can be used to improve future projects.

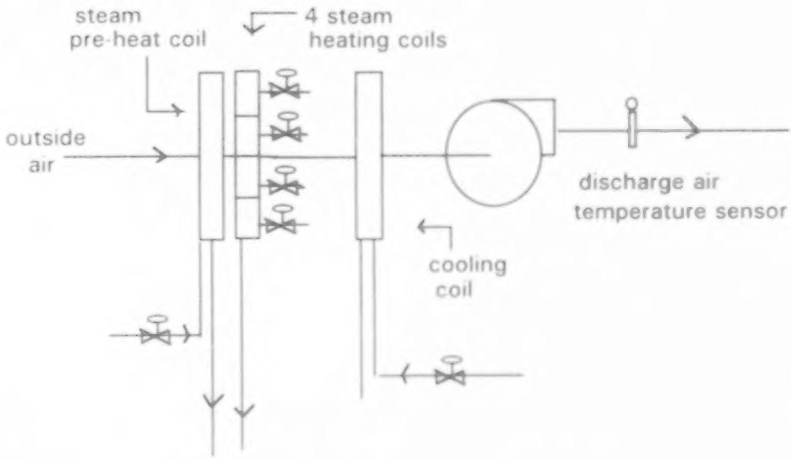
A Design Problem: Error In Sequence Of Operations For Preheat Coils

According to the specifications, "Sequence the multiple two-position steam control valves on the steam preheat coils (upstream coil first) to maintain the desired supply air temperature."

Because the upstream preheat coil provides a temperature rise of greater than 20° F, it cannot be used to maintain a steady discharge air temperature. (See Figure 1.)

Had this problem not been found, the discharge air from the air handling units would have risen well above the discharge air setpoint whenever heat was called for, creating fluctuating, uncomfortably high space temperatures. The excess discharge air temperatures would be accompanied by a waste of steam. Alternatively, the building operations staff would have operated the preheat coil valves manually, creating inefficient use of their time and increased risk of frozen coils.

Figure 1. Air handler.



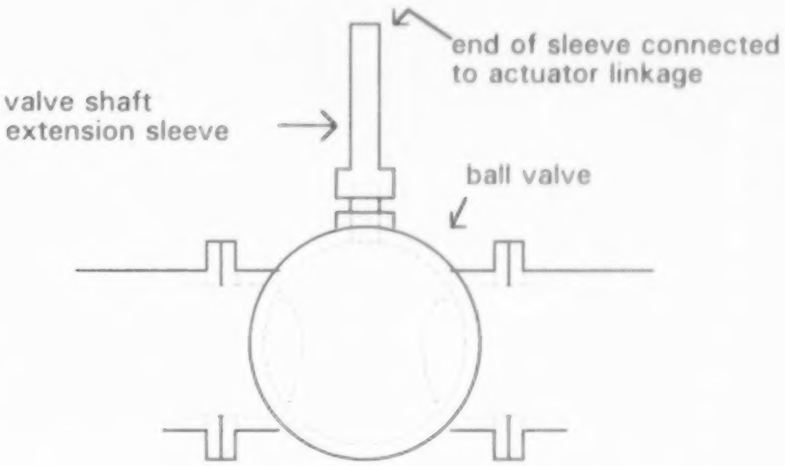
A solution was identified by the commmissioning team during testing and approved by the mechanical consultant: bring the preheat coils on only when the outside air temperature falls below a specified point (e.g., 37°F).

For future projects, it would be helpful to state standard sequences of operation in the university standard design manual and refer to them from other sections. Bringing on preheat coils only below a specified outside air temperatures would be one of the standard sequences.

A Manufacturing Problem: Steam Valves Unable To Close Fully

The Physics/Astronomy building has fifty-nine two-way steam valves in the air handling units. Of those, about 10 percent were incapable of complete closure at the end of functional performance tests. The adapter sleeve extending from the ball valve shaft to the actuator was made of a softer metal than the valve shaft, causing the contact surface of the sleeve to deform with use and become unable to move the valve through its full range of motion (see Figure 2).

Figure 2. Steam valve used in air handlers, showing shaft extension sleeve that failed.


end of sleeve connected to actuator linkage
valve shaft extension sleeve
ball valve

The contractor replaced all valve shaft extensions with cylinders of a tougher metal at no extra cost to the university. Since then, the replacement cylinders have failed in the same manner as the original components. Another set of replacements has been proposed. Ongoing failure of these components results in wasted steam and requires routine attention from the operations staff.

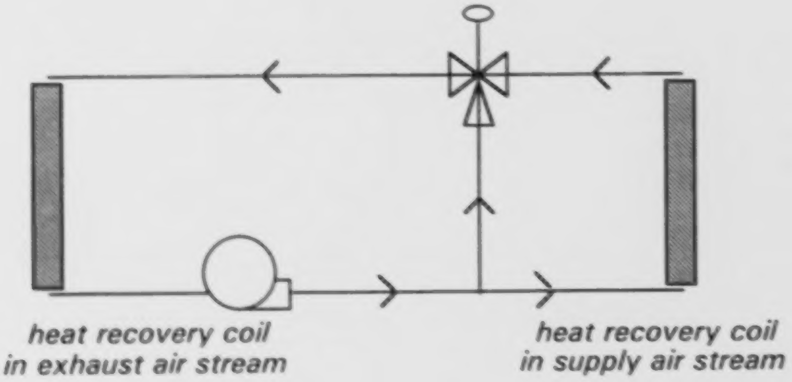
This finding illustrates an important element of commissioning: sometimes determining a workable solution is far more difficult than finding the original problem. For that reason, 1) problem-solving costs need to be contractually assigned to the party who has created the problem, and 2) solutions too need testing. Fatigue testing of actuated steam valves should become part of future commissioning.

An Installation Problem: Heat Recovery Valve Action Reversed

One of the air distribution systems has a "run-around" heat recovery water loop that transfers heat from the exhaust to the supply air during cold weather (see Figure 3). During FPTs, the control action was reversed for the valve that determined the rate of flow through the coil in the supply air.

Reversed valve action was easily corrected once it had been pointed out. Had the problem not been found, however, the heat recovery system would not have saved energy.

Figure 3. Heat recovery water/glycol loop.


heat recovery coil in exhaust air stream
heat recovery coil in supply air stream

Control problems affecting nonessential systems like heat recovery may go uncorrected for a long time in large institutions. As a result, a capital investment in heat recovery equipment can increase the pressure drop through the ventilation system (due to the heat exchangers) without reducing heating consumption. When valve action is reversed, or not clearly identified on the computer screen, it is often because the intent of the design is not well understood by the control company. Commissioning tends to reduce ambiguity and confusion in the control system.

Evaluating The Costs And Benefits

The Cost Of Commissioning

Commissioning the Physics/Astronomy building automation system cost $149,359, including:

- $65,000 for the commissioning agent,
- $44,957 for the control contractor,
- $39,402 for university operations staff time.

The total doesn't include administrative and engineering costs, nor does it include the cost of the control contractor's participation in PTP (in this case only nominal), which was part of the base construction contract.

The cost of commissioning is often estimated as a percent of the cost of the systems commissioned. At Physics/Astronomy, the cost of commissioning, including contributions by the commissioning agent, the control contractor, and university control shops equaled 29 percent of the cost of the control system, or 1.9 percent of the mechanical system cost.[10]

When full mechanical and electrical systems are commissioned, commissioning will tend to run at a far smaller percent of system cost because BAS testing uncovers problems with fire alarm systems, emergency power systems, and the HVAC equipment controlled by the BAS.

Cost Of Commissioning vs. Cost of Debugging Problems Later

If operations, maintenance, and capital budgets are viewed cumulatively rather than as in competition, commissioning may be seen to reduce the total, long-run cost of debugging postconstruction problems by bringing together the project's designers and contractors at a time when 1) they are still available, and 2) the project is fresh in their memories.

The potential cost effectiveness of problem solving through commissioning can be inferred from several observations made in commissioning Physics/Astronomy.

- The contractor was present during testing, providing opportunity to develop a consensus between the contractor and the owner's representative about the nature of the problems observed.
- Commissioning formalized on-site observations, reducing the likelihood of disagreement and the possibility of misdiagnosis, and increasing the likelihood of timely, effective corrective action.
- The commissioning agent contributed expertise which was helpful to the contractor in understanding the design, and helpful to the designer in identifying weaknesses or errors in the design.
- As an independent party, the commissioning agent was effective in coordinating solutions between the controls contractor and mechanical design consultant.
- In-house building operators and engineers may not have had time to introduce effective problem solving after occupancy. Solutions generated in the absence of commissioning may not have been as well thought out and documented as those that were generated out of commissioning.
- If solutions are introduced ad hoc, they may be more difficult to document than solutions introduced when the designer is still available for input and the project documents are still being finalized.
- The cost and occupant-inconvenience of corrective action would have gone up after occupancy.

- Some problems found during commissioning, such as loose connections between the damper actuator linkage and the damper shaft, probably would have been corrected at the owner's expense by the owner's staff had they not been caught during commissioning.[11]

The potential reduction in the cost of debugging construction problems would apply to energy conservation measures (ECMs) as well as general HVAC systems. If a utility decides that the cost of conservation includes a quality control mechanism to protect the link between analysis and ongoing performance, the lowest cost strategy for applying that investment may include commissioning prior to payment.

Enhanced Realization Of Design Goals

Commissioning moves a project closer to its design goals by debugging the design and strengthening contract enforcement. At the Physics/Astronomy building, the design goals for the mechanical systems were (in approximate order of decreasing importance):

1. Occupant safety.
2. Support for research.
3. Flexibility of space use.
4. Comfort (thermal and auditory).
5. Operability and repairability (reasonable labor and parts costs and reliable long-term system performance).
6. Energy efficiency.

With the exception of auditory comfort, commissioning of the Physics/Astronomy building improved the project's ability to meet all of the above goals.

Impact Of Commissioning On Energy Efficiency

There are three categories of energy savings that may arise from commissioning in new construction and existing buildings:

1. Improved realization of energy conservation measures (specific design decisions made to increase energy efficiency).
2. Energy savings from commissioning which is focused on energy efficiency, applied to design elements which were not selected specifically for energy efficiency.
3. Energy savings obtained by commissioning a project where design and commissioning were driven primarily by other (nonenergy) goals.

Commissioning Specific Energy Conservation Measures

To the extent that a building is designed for energy efficiency, commissioning will help achieve that goal.

Commissioning Focused on Energy Efficiency

Although the commissioning process is most effective when it has the same focus as the design, commissioning also can have independent bias, expressed by the choice of tests.[12] A commissioning effort can therefore emphasize energy efficiency 1) in new building for which energy efficiency was a low priority in the design and 2) in "retrocommissioning" inefficient existing buildings long after they are built. In the case of Physics/Astronomy, the priorities in commissioning were the same as in the design, except that a greater emphasis was placed on operability and reliability.

General Building Commissioning

How, then, does HVAC commissioning affect energy efficiency in a project where the design and the commissioning effort are both primarily driven by other objectives?

Some of the problem solving accomplished by general building commissioning does not reduce energy consumption.[13] If, for example, a group of supply fans that needs to start up automatically in parallel fails to do so because of a faulty proof-of-flow switch, ventilation, thermal comfort, and building pressurization will suffer temporarily, and operations labor costs will increase, but energy will be saved during the few hours of discomfort.

Similarly, if a room temperature sensor controlling the HVAC service to a particular space is inaccurate, there is likely to be a period of discomfort before a complaint call is made and the setpoint is adjusted to compensate, increasing the labor cost for operating the building. But the inaccurate sensor is as likely to reduce consumption as increase consumption during the period of discomfort. If it reads low in the winter, energy will be wasted overheating the space. If it reads high in the winter, energy will be saved underheating the space.[14]

A fume hood drawing insufficient air due to a partially closed fan discharge damper might expose the occupant to health risks, but would not increase energy consumption.

Other types of equipment malfunction identified in general building commissioning will indeed reduce energy consumption, some very significantly. Of the problems identified in commissioning the Physics/Astronomy project, a significant potential energy impact can clearly be identified for five (see the following table). Small or uncertain reductions in consumption were not included.

The savings in the table are calculated as the annual savings multiplied by the length of time from when the problem was solved via commissioning to when it would have been solved in the absence of commissioning. The assumed duration of savings ranged from 0.5 to three years. By necessity, the calculations are only approximate, as discussed below under Uncertainties in Quantitative Assessments. The assumed energy costs are $0.24 per therm for natural gas and $0.035 per kwh for electricity.

The two categories of findings which resulted in the highest energy savings were

- incorrect sequences-of-operation for central control valves, and
- leaking valves (particularly steam valves).

Valve problems may go unnoticed—and therefore uncorrected—in some seasons if the heating and cooling systems compensate for each other to cancel out impact on the conditioned space. For example, energy wasted at reheat coils can be canceled out in a VAV system by increased supply air. Likewise, a leaking steam valve at an air handler coil may go unnoticed in the fall and spring if the cooling coils can compensate.

Estimated energy savings.

ID # from Table 1	Description	Potential Energy Savings, kwh/yr	Potential Energy Savings, all fuels, $/yr	Number of Years of Savings	Total $ savings = yrs x $/yr	Assumptions	Estimated Savings, kwh/yr	Estimated Energy Savings, all fuels, $/yr
1	Pre-heat coil control sequence	0	$7,245	0.50	$3,623	When sat exceeds stpt, 2/3 of added heat assumed to be useful by displacing reheat, 1/3 causes discomfort. Multiply svgs by .75 because closed loop control would cause cycling.	0	$3,623
2	Steam valve leakage	81,824	$7,894	1.00	$7,894	Assumes 6 of 59 coils leak; one of them a preheat coil. 3/4 leaked steam wasted when oat > 62 (rest displc reheat). Leaking coil output 60% cap. Cooling energy wasted during summer when oat > 65.	0	Problem not yet solved.
3	Heat recovery valve control action backwards	0	$2,467	2.00	$4,934	Calculate loss of heat recovery.	0	$4,934
6	Damper actuator linkages not securely mounted on damper shaft - slippage	63,120	$2,209	1.00	$2,209	Economizer for free cooling with outside air looses 20% of the flow due to maximum open position of 45 degrees for outside air dampers.	63,120	$2,209
7	Leaky duct pen-iterations at campus cooling water coils	921	$171	3.00	$513	Assume 100 cfm leaks from each of six air handlers.	921	$513
	TOTAL	145,865	$19,986		$19,173		64,041	$11,279

At Physics/Astronomy, most of the energy savings from commissioning are savings in steam generated at the central plant by natural gas boilers. Electricity savings resulted from correcting duct leaks and loose attachment of outside air (economizer) damper shafts to the damper actuator linkages.

The estimated total energy saving thus calculated is approximately $11,000. Had fatigue testing of steam valves been successfully introduced for both the installed and the replacement parts, the estimated energy savings from commissioning would have been $19,000.

Overall building commissioning—distinct from commissioning specifically for energy conservation—does save energy. Correcting certain problems offers multiple benefits, of which energy conservation is only one. At Physics/Astronomy, where the scope of testing was the building automation system, tests of the valve control sequences and the steam valves offered the greatest potential energy savings, and therefore, greatest cost benefit.

Types Of Problems Best Addressed By Commissioning

Turning now to a more general assessment of commissioning, the success of commissioning for specific test findings can be qualitatively rated by

- The potential adverse effects of leaving the problems found during commissioning unsolved, and
- The degree to which they were solved as a result of commissioning.

According to these criteria, commissioning at the Physics/Astronomy project was more successful in addressing some types of problems than others.

Effective solutions were most readily introduced for design and installation errors which could be corrected easily and inexpensively by applying a strong knowledge of 1) HVAC design, 2) testing, and 3) the contract language of the specific project. Some of these errors, if left uncorrected and undiagnosed until after occupancy, could have caused considerable confusion, compromised comfort or safety, and/or wasted energy. The decoupling of the preheat coil, loose damper linkages, inability to return to normal power in a timely manner, improper operation under fire alarm, and incorrect operation of the heat recovery run around loop valve fall under this category.

The impact of commissioning on on-site calibrations was less dramatic. Although commissioning probably expedited proper recalibration, the process was not successfully completed until after the control shop technicians began operating the building. The process might have been similar in the absence of commissioning. Calibration of flow switches and MCCs fall under this category. These problems greatly inconvenienced occupants because they caused ventilation fans to shut down unexpectedly.

The solutions that were least successful involved faulty equipment selection, such as round damper shafts, faulty manufacturing (e.g., steam valve extension sleeves), and design problems for which solutions are not easily developed, such as building pressurization, which is notoriously troublesome.

Manufacturing problems may be difficult to solve because the commissioning agent (and often even the university mechanical engineer) doesn't work directly with the manufacturers' factory engineers. The factory engineers are often more capable than any other party of understanding the cause of failure and identifying the least-cost avenues for a solution satisfactory to the owner. Solutions to manufacturing problems also tend to be more expensive.

Nationwide development and application of standardized tests and third-party testing to support certified submittal and nameplate ratings may offer a more viable long-run source of quality control (for faults in manufacturing) than on-site testing. In the foreseeable future, however, on-site testing is essential as a check to manufacturer ratings and to fill the gap where they are not available.

Uncertainties In Quantitative Assessment

Benefit Assessment

Energy savings calculations have been offered in this case history to illustrate the types of assumptions involved, and to provide round numbers. It is important to understand the degree of uncertainty in the numerical inputs to avoid the temptation to create a more elaborate set of calculations than is warranted. The gross assumptions should be examined and refined, but the value of time-consuming analytical tools has to be questioned.

The benefits of commissioning include increased occupant satisfaction, safety, and productivity; reduced retrofit costs (including design, construction, and management); reduced operations labor; reduced energy costs, and solution of problems when the costs may still be born by the contractors and designers. Some of the challenges in quantifying these benefits are listed below.

- It is difficult to judge how much the contractor's (pre-commissioning) performance may have been worsened or improved due to the presence of commissioning. It was the impression of participants in the Physics/Astronomy project that this effect is potentially large in either direction. The baseline therefore is not strictly equal to savings resulting from correction of the problems uncovered during testing.
- It is difficult to know when a problem would have been found and how it would have been addressed if it had not been found in commissioning.
- The level and duration of success achieved by solutions introduced through commissioning can't be assessed until they have been in place for a long period.
- If a malfunction causes problems for the occupant, the operations staff will often compensate for errors in design, installation or manufacturing by introducing temporary solutions to tide the occupant over until retrofit funding or warranty enforcement provides a permanent resolution. These informal solutions (such as use of manual shut-off valves to mitigate the failure of the automatic steam valves) combine labor, energy, and comfort costs in ratios which are difficult to pin down because they are influenced on a day-to-day basis by the weather, the degree of occupant complaint, and availability of labor, and more permanently by the priority placed on energy efficiency. It

is common among large commercial buildings for temporary solutions to stay in place for years.

- Commissioning may reduce some of the hidden costs of TAB: time spent identifying problems which need to be solved before balancing can proceed.[15]
- Salaried staff managers and engineers may not bill their time to specific projects, so costs for postoccupancy retrofit and maintenance are not documented.

Cost Assessment

The costs of commissioning are also difficult to pin down. The cost of the contractor's participation may be included, but not separately itemized in the construction contract. Even if the contractor's involvement were separately itemized, what should that cost include? Should it include work that is part of standard specifications but rarely enforced, or work that is performed by some contractors as standard practice, but not by others? Would execution of the manufacturer's standard start-up and checkout procedures and submittal of the completed forms be considered part of commissioning? The labor costs for the UW staff mechanical engineer and project manager in overseeing the development of the commissioning agent contract, commissioning plan, test schedule, test procedures, test reports, and recommended actions may not have been recorded. (They may well be less than the avoided management and staff engineering costs of debugging problems after occupancy, but both can be difficult to pinpoint.)

An Uncommissioned System

The potential benefits of commissioning can be better understood by examining an uncommissioned system. The process chilled water at Physics/Astronomy offers an example of a system that might have benefited from commissioning.

Defining Occupant Needs

During the early programming[16] phase of each project, design professionals identify the needs and goals of the client. Years later, at the end of construction, the project comes full circle as the occupants begin to move in and observe the outcome. They may or may not be pleased with what they see. Dissatisfaction can arise through a number of common occurrences.

- A client may not have time to become thoroughly involved in programming,
- A client group may include individuals with strongly divergent opinions,
- A client's perceived needs and goals may change between the programming phase and the date of occupancy.

In a highly specialized project such as the Physics/Astronomy building, the client, who may have never been involved in design of new construction before, is often unaware of the characteristics in the former facility that made it possible to execute his or her work properly. If the designer is not experienced with that particular type of work, the proper questions don't get asked, or they get asked and the client doesn't know the correct answers.

When the occupants moved into Physics/Astronomy, they discovered that the process chilled water system was designed to provide chilled water at temperatures and pressures which many of the occupants could not use. The new process chilled water system was actually a step up from what the physics department was used to in the older building, where lab equipment was cooled with city water. However, because the experimental equipment was designed for operation on city water, it had problems operating when hooked up to the water system in the new building. The pressure was inadequate (20 psi instead of 40-50 psi), and the water temperature too low (42° F instead of 55° F).

The commissioning agent is not normally charged with the task of comparing the original programming goals with the installation. However, when the contract language is ambiguous, the design calculations and basis for design are studied for clarification. If those documents fail to resolve the confusion, the underlying design intents or department requirements are examined. The commissioning agent becomes, in this way, a link between the various phases of the project on any issue which appears problematic.

The story of the process chilled water system at the Physics/Astronomy building raises not only the question of which systems should be commissioned, but also whether commissioning should routinely include examination of critical elements of HVAC programming to determine whether or not they are being met. This task is a natural extension of the commissioner's job of comparing the installed project to the design. The programming documents may seem outdated and sketchy by the time a commissioning agent is hired, but the commissioning agent's questions would be useful for bringing forth the information needed to fill in any gaps. As a neutral (nondesign, noncontractor) party, the commissioning agent has the advantage of viewing the project with fresh eyes, which may give him or her the distance needed to identify any serious discrepancies between the user's needs and the design.

While commissioning probably would not have eliminated the Physics/Astronomy process chilled water problems, it might have generated a solution before occupancy, thereby reducing occupant inconvenience and disappointment.

Project documentation can itself greatly facilitate continuity between the client's needs and the evolution of the final product by

- Producing a programming document that is kept alive and periodically updated throughout the major decisions and negotiations concerning HVAC system design requirements ensures greater accuracy by minimizing dependency on informal minutes and human memory. The design and construction process takes several years; there may be changes in personnel between start and completion.

- Creating a complete set of design documents that explains the basis of design, or the "design intent." Information should include such details as assumed setpoints and the operating conditions and diversities assumed in sizing equipment (design conditions). The programming document should be referenced in, and attached to, the basis for design.

- Developing rigorous programming and design documents reduces the time, and therefore the cost, the commissioning agent spends comparing the two, and reduces the probability that the commissioning agent will find discrepancies between design intent and client requirements.

Bypasses, Filters And Flow Controls

During start-up and move-in, a number of other problems with the process chilled water system were also uncovered.

- Uncontrolled bypasses (supply to return) at the end of the floor-by-floor supply chilled water loops prevented adequate pressure drop across the individual loads. The bypasses had been used for flushing the system.
- Dirty construction strainers had been left in place, further reducing available gpm through experimental equipment.
- The proper control of the piping common to the primary and secondary chilled water loops was unclear. Because this is a primary/secondary distribution system, the secondary loop was presumably designed for variable flow through the secondary pump, but no three-way valve, throttling valve, or VSD had been installed at the secondary pump. As a result, the distribution system was riding the pump (flow vs. pressure) curve.

Whether or not these problems would have been uncovered earlier through commissioning would depend on the commissioning scope of work. Prior to occupancy there are often no loads on the process chilled water system because experimental equipment hasn't yet been transferred into the new building. The scope of work for commissioning would need therefore to include installation of a bypass per floor to simulate a load in order to examine pressure patterns. If that had been considered, the uncontrolled end-of-the-run bypasses probably would have been used in commissioning and removed prior to occupancy. Checking strainers would typically be part of commissioning, as would clarification of flow control through the pumps and the common piping between the primary and secondary loops.

Commissioning And Project Management

In some respects commissioning reduces the work of the owner's project manager, because the commissioning agent's time, energy and expertise increase the speed with which problems are discovered and taken care of.[17]

In other ways commissioning increases the work of the owner's project manager, first in supporting the commissioning agent, then in making sure that other parties don't shift their contractual responsibilities onto the agent and the owner's operations personnel involved in commissioning.

Supporting The Commissioning Team

If the commissioning team is not made up of members from the design team or the contractors, commissioning increases the number of project participants. In that case, project management needs to assure that the new players are included in meetings and distribution lists that will allow them to work effectively. Particularly critical is distribution to the commissioning agent of punch lists, change orders, and design clarifications relevant to commissioning.

Discrepancies found during commissioning need to be communicated to the contractors and integrated into the punch lists being developed, and the commissioning team needs to be kept abreast on the follow-through to identified discrepancies.

On the Physics/Astronomy project, the commissioning agent was well supported by the UW mechanical engineer's coordination, and decisions were made with a minimum of meetings by keeping lines of communication open throughout the process.

Holding The Other Players Accountable

1. Two Views of Commissioning

Ideally, commissioning increases the accountability of the designer, contractors, and manufacturers so that they do a better job *prior to testing* than they would otherwise. On the other extreme, the addition of a commissioning agent may give other (noncommissioning) parties the impression that they are relieved somewhat of their responsibilities in quality control. If this sense of relief has not been reflected in a lower cost of services, the owner has clearly lost out.

When asked about the value of commissioning to the Physics/Astronomy building, the mechanical design consultant for the Physics/Astronomy building replied that contractors on commissioned jobs do less postinstallation checkout and testing of the equipment (before commissioning) than they would in the absence of commissioning.

On the other hand, the general contractor did an outstanding job, well above the norm, of coordinating work on the fire and life safety system commissioning, including development of a detailed "design intent" document.

There are a number of steps the owner's project manager can take to encourage other parties on the project to feel more, not less, accountable in the presence of commissioning.

2. Avoid Transfer of Costs and Liability to Owner

Commissioning is cost effective if most equipment passes the PTPs and FPTs on the first round of tests. If the shop personnel and commissioning agent get bogged down in extensive problem solving and retesting, liability and costs are shifted unfairly to the owner, and the costs of commissioning can skyrocket.

The construction contract should therefore impose the cost of problem solving and retesting on the party responsible for the problem, and the costs of problem solving and retesting by the commissioning agent should be tracked separately (in their contract and invoices) from the first test costs. This provides some motivation to the other parties to solve problems before PTP and FPT.

At Physics/Astronomy, since commissioning was added to the project after the design had been completed, these issues weren't addressed within the construction documents. Neither the commissioning agent's troubleshooting nor retesting costs were reimbursed by the parties responsible for the problems being corrected. However, the costs of the commissioning agent were still well contained because the necessary corrections to the BAS system were fairly straightforward, no other systems were commissioned, and the commissioning agent and the university mechanical engineer managed the FPTs effectively.

The contractor did shift his contractual obligations onto the owner through the PTP process at Physics/Astronomy, resulting in increased costs to the owner, but not, in this case, any transfer of liability.

The possibility of shifting costs and liabilities from the responsible parties onto the customer through commissioning can further be limited by structuring the commissioning contract to prevent transfer of budget for the first round of tests into troubleshooting and retesting.

3. *Correcting Problems Before PTP and FPT*

At project completion, check-outs generally proceed from the simple to the complex. The complex check-out procedures, such as FPTs, become more costly and less meaningful if problems which should have been identified in earlier tests remain outstanding during the period scheduled for complex test procedures. For example, the heating hot water wasn't available in some parts of the system during PTP. As a result, tests did not uncover that some of the reheat valves were installed backwards, and were therefore unable to close fully.

Contractor Precommissioning Tests. The basic construction contract often includes a number of start-up, owner-witness, and acceptance test requirements independent of commissioning. The project manager can reduce the cost of commissioning by making clear from the start that this type of contract language will be enforced. Project management will be significantly facilitated if a test matrix listing contractually required tests, the specification sections in which they are called out, and who is to perform and witness the test is created as part of the design documents.

The UW construction manager for the Physics/Astronomy project generated an excellent test matrix. The Agreement for

Architectural Services described the following service under the section Additional Services and Reimbursables.

> *Providing a list and completed matrix of the tests and inspections required for the Project in a format approved by the Owner.*

Such additional services only become effective if invoked elsewhere in the contract. It appears that this was not selected for Physics/Astronomy, but it should be considered for future projects as a way to encourage a high level of attention to testing and contract enforcement during the design process.

The quality of contractor precommissioning work can be further improved by a construction contract requirement that the contractor submit the manufacturer's literature stating the recommended/required start-up procedure, and submit the start-up report within a specified time period (e.g., seven days) prior to notification of completion.

Design Consultant Punch Lists. The cost of commissioning will be reduced if the mechanical and electrical design consultant punch lists are complete and the identified problems addressed as much as possible before commissioning tests. Each problem that remains drives up the cost of each subsequent phase in project completion, through costs of rediscovery, discussion, distortion of test procedures, etc. The standard contract with the design consultant will require development of a punch list. The Physics/Astronomy Agreement for Architectural Services states:

> *Architect shall conduct prefinal inspection and prepare check-lists of corrective items, make all inspections (all disciplines), including at least one reinspection, determine the date of dates of Substantial Completion, and the date of Final Completion.*

The design contract should describe in more detail the procedure and scope of work involved in developing the punch list.

Testing Adjusting and Balancing. The owner's project manager can reduce commissioning costs by obtaining a written weekly summary from the TAB company of 1) what TAB work was completed, and 2) what discrepancies, problems, and design questions were identified during the course of the week.

Moving TAB forward efficiently is critical because otherwise FPTs may need to be executed before TAB has been completed or after occupancy. (If the construction manager can assure that the PTP is completed before the TAB, it may in turn reduce the time required for TAB work by minimizing problems encountered in the BAS.)

At Physics/Astronomy, the TAB company provided good punch lists to the university. One of the serious problems identified—leaking pump isolation valves—continues to be a problem to this day. Another problem—fan backwheeling and trouble restarting manifolded fan systems—was solved after commissioning using the mechanical engineer's recommendation made during TAB to change the end switch setting from 80 percent to 12 percent open.

Flushing. If flushing is not properly executed, the number of problems found during commissioning can increase dramatically. The owner will want, therefore, to monitor the flushing and make sure that dirty filters and temporary bypasses are removed when the work is completed. To facilitate management of flushing, the construction contract should require submittal of schematic drawings which show valve positions and locations of any temporary pumps and/or bypasses (identified clearly as such) to be used for flushing. Alternatively, the mechanical design consultant could be required to produce such a schematic as part of the contract drawings.

Several of the postoccupancy problems at the Physics/Astronomy project were caused by inadequate completion of flushing activities. The impact of commissioning in this case was slight, because none of the hydronic systems was commissioned.

4. Moving from Problem Identification to Solution: Contract Enforcement

Sometimes discrepancies between contract requirements and installation found through commissioning remain unresolved unless the owner's project manager is willing to with-hold payment from the contractor until the problem is taken care of.

At the Physics/Astronomy project, the contractors were generally cooperative in addressing problems identified during commissioning, relieving the university of the need to use strong-arm tactics.

5. Realistic Expectations

The term "building commissioning" is deceptively all-inclusive. It is important that project managers understand and communicate the specific scope of work contracted to the commissioning agent so that areas which are not covered get attention from other parties.

Similarly, any commissioning activities contributed by in-house staff should be defined and made clear to contractors and design consultants as early as possible.

The scope of work that falls to the commissioning agent is defined in two ways:

1. By systems to be commissioned.
2. By the degree of testing, problem solving, and retesting for the systems to be commissioned.

It is particularly helpful to emphasize critical equipment that is *not* going to be commissioned, so that responsibility for facilitating contractor acceptance test schedules and reviewing contractor acceptance test results can be assigned elsewhere. The creation of a test matrix, as described above, is the first step in managing a project that will be commissioned.

Mechanical equipment such as cold rooms or fume hoods specified by the architect deserve special attention from the project manager, to make sure that the appropriate in-house staff and/or commissioning agent reviews submittals and observes contractor start-up and acceptance tests.

For those systems which are commissioned, the construction manager needs to keep in mind that solutions to the problems found will involve several parties. The numerous components of successful problem solving are outlined below. The need for full coverage is somewhat greater for serious problems, but small problems too can become very time consuming if the groundwork for solutions is not properly established.

1. Examination of the report of the problem to make sure it is complete and valid.
2. Development of further in-depth testing or trend logging to provide additional problem diagnosis if warranted.
3. Distribution of well formatted test data to interested parties
4. Development of consensus on interpretation of data among affected parties.
5. Understanding associated documents contract, submittals, RFIs, COs, minutes.
6. Determination of who is contractually responsible for paying for the solution.
7. Understanding what will work technically.
8. Understanding what will work within the budget and scope of opinions put forward (facilitation of agreement).
9. Examination of the proposed solutions to make sure quality control is in place.
10. Motivating the responsible parties to perform necessary tasks (decisionmaking, documentation, design, manufacturing, installation, testing, test reviews).
11. Energy/lobbying/persistence to get the process moving, against the inertia of overwork and sinking profits.
12. Tracking the solution.
13. Retesting and evaluation of retest.
14. Initiation of corrections if solution not satisfactory (go back to step 1).

Although the commissioning agent may have the capability and scope of work under contract to execute many of these functions, the project manager will need to make sure that the steps not covered under the commissioning contract get filled in by other parties.

Successful problem solving involves a combination of skills in literacy, record keeping, facilitation, bludgeoning, and technical savvy that rarely exist in a single individual. The commissioning team will include one or more of the design consultants, members of the owner's staff, contractors and possibly an independent commissioning agent. The roles of each participant will be determined in broad strokes by the relevant contracts, but will also be determined by the respective personalities, interests and areas of technical expertise of each player. The exact make-up of the commissioning team may be difficult to anticipate at the time contracts are signed, because change in personnel tends to intervene prior to project completion. So the project manager will want to monitor the progress of problem resolution after commissioning starts, to make sure that the essential elements are in place. Where a gap exists, some member of the owner's staff may serve as a valuable bridge.

The general contractor can play an important role in commissioning, because objective test results serve him or her as a valuable tool in debugging the project. Like the commissioning agent, one of the general contractor's roles is to make sure that the work of the subcontractors is well coordinated for intersystem functionality. If the general contractor chooses to work positively with the commissioning team, money can be saved on all sides as effective pressure is brought to bear on subcontractors to correct the identified discrepancies in a timely manner.

The owner's staff must make sure that test results are clearly and efficiently communicated to the general contractor and design consultant so that the nature of the problem is properly identified, and so that test results are considered carefully before initiating solutions. In the same way that a contractor will tend sometimes to ignore problems with construction, the independent commissioning agent will sometimes inadvertently identify a "problem" with design or construction which turns out not to be a problem once the agent has a better chance to consider the situation. It is precisely this difference in perspective which is most valuable about the commissioning process, because it permits a dialogue conducive to fast solutions.

The owner's staff will facilitate commissioning by assuring that all sides are allowed to throw light on any (apparent) serious discrepancy that arises in commissioning.

In development of the Physics/Astronomy commissioning contract, the ME explicitly assigned a large portion of the follow-through to the commissioning agent. The commissioning agent was thus put in charge of coordinating solutions with input from the design consultant, contractor, and the university. This worked well, partly because both were calm, systematic, and judicious by nature. There was no need to arbitrate any disagreements between the commissioning agent on the one hand, and the design consultant and contractor on the other. The fact that only one system was being commissioned, combined with the inclusive management style used by the commissioning agent and ME, made it possible for all parties to understand their roles in problem solving and retesting. The only confusion occurred after building occupancy, when problems were uncovered in systems that had not been commissioned. A cry to the effect of, "How can we have these problems? This project has been commissioned!" was heard. There is a healthy tendency when writing up a commissioning contract to restrict the budget to only the commissioning that will be most beneficial. Under such circumstances, commissioning can be held accountable only for those systems for which it was budgeted.

The Construction Contract

Quality control is most inexpensively obtained by developing a clear understanding during the design process of what each party must do to get paid under the construction contract.

The design should be fully developed and, if possible, should be reviewed by the commissioning agent before it goes to bid. A well defined scope of work for the commissioning agent's review and the review write-up requirements will assure that 1) specific tasks are performed, and 2) a high cost due to uncertain scope of work is avoided. The scope should include:

- Evaluation of any element of the specifications which address commissioning, performance specification, start-up and acceptance testing, and submittal requirements for equipment to be commissioned.
- Examination of specifications of the BAS system and its use in testing, to assure that it will serve as a use-

ful commissioning tool. Specifically, check specifications for sensor accuracy, type, and location, as well as actuated damper and valve type, size, and location.

- Review of the sequences of operation for clarity, completeness, and logic.
- Review of the man-machine interface, trend logging, graphics, and alarm specifications.
- Comments on the specifications, or contract, for testing, adjusting, and balancing.

The Cultural Impact Of Commissioning

Because commissioning is currently a popular new "fad," it has an aura of sophistication and excitement. Indeed, the first participants tend to be forward thinking types who worked in this direction before it was widely recognized as a worthy cause. It comes therefore as somewhat of a surprise to the uninitiated that commissioning involves a lot of patient, repetitive, nitty-gritty work.

In fact, one of the more useful insights one can take away from the first case history of commissioning at the University of Washington is a recognition that commissioning consists of simply focusing on the essential details that no one else really thought it worth their time to bother with. Commissioners are paid to notice that which is too small, too pragmatic, too dirty, or too mundane for people in high places to be concerned about.

The upsurge of interest in commissioning has come about because occupants have run into too many problems with glorious new buildings. Although legislators, alumni, and budget managers may find architecture more exciting than engineering, and new construction more exciting than operations, the degree to which we can ignore that which is boring has begun to become clear, and biases are consequently shifting, on several fronts.

From Architects to Engineers

Architects run the design of large projects; engineers do not. In general, architectural elements fascinate architects and the client's high administrative officers, and engineering elements do not. In fact, the difference between a viable HVAC design and a weak one when presented by a self-confident, eloquent HVAC designer may be imperceptible to the highest levels of design management. This is not a criticism of administrative officers or architects, it is just a description of an inevitable weakness in the system.[18] If HVAC were treated as a more vital and interesting part of design and construction, there would be less need today for building commissioning.

From Design to Construction

There is money to be made in construction, and no one will deny that the people who earn a living that way only do so through a combination of character and expertise which is daunting to those of us who wouldn't make it in that field. No one would consider construction boring. Nevertheless, the evolution of a project between the drawing board and a physical reality sometimes receives inadequate attention from people who participate in design.

From Capital Projects to Operations

Educational institutions across the country tend to have an easier time raising money for new construction than operations. Legislators, alumni, and the public at-large seem to have more interest in construction of grand buildings than making sure university facilities are useful to academicians. Commissioning is a small concession to the fact that occupant satisfaction depends to a large degree on such details as thermal and auditory comfort, indoor air quality, and HVAC response under fire alarm.

From Sales to Manufacturing and Installation

The "new" and "improved" product is typically easy to sell but difficult to manufacture and install successfully, for a number of reasons.

1. Talk is cheap.

2. For many of us, concepts are more fun than reality, and more easily understood.

3. By the time the building is finished and occupied, problems are put under the category of operations rather than capital projects, so their solution becomes free in the minds of those who are more interested in capital projects.

Increased interest in commissioning suggests that clients are willing to spend a little more money to assure that what goes into a building will work and that they will spend a little less time trying to move on to the next generation of technology before the current one has been debugged.

From the Big Chiller to the Little Valves

Even within the world of HVAC, even within the world of the tried and true, some equipment is considered interesting, because it is expensive and/or complex. The small, inexpensive HVAC components such as valves, dampers and sensors are likely to be expensive operationally, specifically because they seem unimportant to designers and managers. The small parts are not easy to address through early commissioning efforts, but will no doubt be covered with increasing skill as the field matures.

From White Collars to Blue Collars

There is one group on any project who knows all of this in excruciating detail: the field technicians on the client's staff. Commissioning is more than anything a recognition that people who operate buildings do valuable work that needs to be supported through budget allocation, design, manufacturing, installation, start-up, and testing.

Field technicians know what makes a building work and what makes a building fail. They know that many occupants care as much about HVAC as architecture; they know that valves and sensors are as vital as chillers and control panels. They know that lack of attention to the nitty-gritty details in design, manufacturing, and construction can lead to glitzy projects that don't work. But the building operators have not traditionally had a voice in how capital budgets are directed.

Conclusion

It is the role of commissioning to communicate the vitality of pragmatism; to communicate the excitement and sense of accomplishment that comes from creating projects that work and that satisfy the occupant. By concentrating on the details, the commissioning agent can distinguish between the promise of the design and the reality of operation. While the customer pays more for design, manufacturing, and construction, the outcome is a fully functioning building that serves the occupants and the men and women responsible for keeping the facility in operation for many years.

Notes

Acknowledgments

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Special thanks to John Heinz at the University of Washington for his guidance and support for the commissioning effort, and to the Bonneville Power Administration for setting up the grant to create this case history.

1. Design operating conditions are the conditions that correspond to the "maximum" heating and cooling loads for which the system is being designed, assuming non-emergency circumstances. Nondesign operating conditions include emergency power, fire, and heating and cooling loads that occur all but a few weeks of the year.

2. Innovation has been driven by environmental, health, and energy efficiency concerns and applied new technologies, particularly in electronics, as they became available.

3. At one point there was discussion of providing two rooms: one for controls and the other for the rest of operations and maintenance. Controls require a particularly high level of security, which may include isolation from the operations staff that work on non-control building systems. Since there is only a single O&M room at Physics/Astronomy, the control shop initially requested and received installation of special locks to prevent entry of any staff without the presence of a member of the control shop. That solution is going to be revised to provide installation of a cage around the computer terminal so that all the shops can use a single room, while restricting access to the control system.

4. System testing can run into extreme delays, reiterations, and useless test results if there are widespread component level failures, because of the vast number of components involved in the operation of each system. There are sometimes several witnesses to system and intersystem tests, so the labor cost of aborted efforts is high. However, in the opinion of the this author, activities of the independent commissioning agent may shift in the future entirely into whole-system and inter-system testing, to limit the owner's commissioning costs. This would leave it up to the contractors and designers to sort out and correct the reasons for any test failures, including component malfunction.

5. This resulted partly from the fact that section 15900 of the specifications required the control contractor to demonstrate execution of the sequence of operations via trend logs—an element of the contract not pursued because it was seen as overly vague, and redundant to commissioning. The contract specifications contain the following language:

"Under 15890, Mechanical Testing , 3.4, Acceptance Testing, After all mechanical and electrical systems and controls are 100% complete, balanced, and in proper operating condition, test-run systems as specified herein. Test Period: Minimum of three eight hour days with continuous supervision and monitoring. Provide three days notice to the Owner prior to start of testing. During these test periods, keep a continuous trend log of equipment performances, (utilizing the DDC temperature control system) including setpoints, and make hourly logs of designated room temperatures, gpm's, water and supply air temperatures. Submit log and recording charts for approval. If, during the tests, any system fails to perform as designed, immediately correct the defects and schedule a new test."

"Under Section 15900, BAS, 1.7 Commissioning: System commissioning shall be done by the vendor, witnessed by a representative(s) of the UW maintenance shop and as a minimum include the following:

"... Point Test: Check that terminal operates devices or receives information from sensors. Verify calibration of each sensor. Verify manual operation of each actuator. Control Logics: Exercise all control logic packages. Check response to upset, change in setpoint. ... Verify reset control. ... Verify communication with each field device installed. Make end-to-end sensor and actuator checks."

6. The university has found that the most competent test observers invariably feel the urge to execute tests rather than stand by and watch them happen (a preference to be found among some of the best engineering consultants hired as "commissioning agents" as well as among

UW control technicians). As one might expect, the contractor will often encourage this inclination.

7. The specifications should note that the owner's witnesses to on-site testing will not sign any of the contractor's test report documents, but will generate an independent report to be provided to the owner's project management staff.

8. The control contractor's stronger performance in FPTs than PTPs may have resulted from the fact that the first was covered under a separate contract whereas the second was paid for under the original construction contract. If, during the bidding of the project, the control contractor hadn't intended to fully execute the testing called out in 15900, they may not have felt "paid" to do the PTPs.

9. As DDC control systems become more powerful, the possibility of using trend logs to reduce the labor costs for on-site testing attracts increasing attention nationally. Such an approach may require improvement in DDC sensors, and calibration checks earlier in the project, but such an effort would offer multiple benefits, in reduced TAB, FPT, and ongoing operational costs. It is therefore likely to become prevalent as commissioning matures.

10. The contract costs break out as follows.

Mechanical subcontractor contract price:	*$8,032,325*
Controls (under the mechanical total):	*$516,000*
Electrical subcontractor contract price:	*$3,609,877*

11. On the other hand, there are certain cost benefits of commissioning after occupancy. The occupants, in the course of their daily activities, observe and report problems with the building, which makes it possible to focus attention on areas of the building which need it most. Occupied operating conditions are varied, and may be more representative than preoccupancy test conditions. These benefits are gained, however, at the sacrifice of occupant time and satisfaction, and may result in significant ongoing energy wastage that has no perceptible impact on space conditions.

12. There's not enough funding to test for every possible failure of every piece of equipment and building element. Selection of tests therefore introduces a bias independent of the design. (This is analogous to the fact that journalists inevitably introduce a subjective element to news reportage through selection of stories to report, because only a fraction of the daily events can be covered.)

13. Efficiency versus consumption: Efficiency is a measure of the amount of amenity provided per energy input. Consumption can be reduced either by an increase in efficiency or a reduction in amenity level. Since none of the commissioning work discussed here deliberately reduced comfort to save energy, the distinction between efficiency and consumption is not examined.

14. By contrast, inaccurate sensors located in the outside air, mixed air and discharge air at an air handler could under some control strategies

result in wasted energy. At Physics/Astronomy, the outside air and return air dampers are controlled off a mixed air temperature sensor, while the AHU heating coils are controlled off the discharge air temperature sensor. If the mixed air temperature sensor reads high during cold weather, more than the desired amount of outside air may be brought in only to be heated up by the heating coils.

15. Observation by Rick Casault, an independent commissioning consultant in Seattle, on another project.

16. A project "program" is placed on record before the design documents are developed to establish the design goals and constraints.This use of the term programming should not be confused with the BAS software programming, nor with the university's commissioning program.

17. At the University of Washington, project management is handled by a project manager. At the time of construction a construction manager is also assigned to the project. Either or both of these activities may be contracted out. A university staff mechanical engineer assists the project manager and construction manager, and may be asked to handle the commissioning process. On Physics/Astronomy, both the project manager and construction manager were university employees. The UW staff mechanical engineer was given responsibility for overseeing the commissioning agent's work.

18. No doubt there would be equally serious problems with quality control in aesthetics if engineers were to run the design of new construction.

Description of Terms

The following terms are arranged in a family-of-terms relationship rather than alphabetically.

Design Professional	The architect, architect-engineer, or engineer responsible for the design and preparation of construction contract documents for the building.
Commissioning Agent	The commissioning agent reports directly to the owner and is the qualified person, company, or agency that will plan and carry out the overall commissioning process. Or, if the construction contract documents require the prime contractor to take responsibility for commissioning the facility and systems, then the commissioning authority reports directly to the owner and is the qualified person, company, or agency that will be responsible for the commissioning process and review and approve the contractor's plan, schedule, test procedures, and test results.
Test Engineer	If the construction contract documents require the prime contractor to provide a test engineer, then: The test engineer is the qualified person responsible for developing and carrying out the commissioning plan, schedule, test procedures, and all associated requirements as specified in the construction contract documents.
Basis Of Design	A document that records the design criteria and assumptions upon which the design is based.

Design Intent	A narrative description of the systems and their intended modes and sequences of operation.
Commissioning Plan	The overall document, usually prepared by the commissioning authority, which outlines the organization, scheduling, allocation of resources, documentation, etc., pertaining to the overall commissioning process. The plan would be prepared by the prime contractor, if so specified, and then reviewed and approved by the commissioning authority.
Point-To-Point Tests	Tests which verify that all electrical or pneumatic interconnections between components are properly connected between connection points required to induce intended control operation.
Functional Tests	Tests performed with an individual component of a system to determine if that component independently performs the functions intended and produces the capacity specified.
Functional Performance Tests	That full range of checks and tests carried out to determine if all components, sub-systems, systems, and interfaces between systems function in accordance with the contract documents and design intent. In this context, "function" includes all modes and sequences of control operation, all interlocks and conditional control responses, and all specified responses to abnormal emergency conditions.
Functional Performance Test Procedures	Documents describing detailed, sequential steps required to set parameters and conditions required to test component and system functions throughout all intended ranges of operation.
Acceptable Performance	A component or system is capable of meeting specified design performance parameters under actual load.
Substantial Completion	Substantial completion is a legally recognized point in time that allows the owner to take occupancy of the facility even though there is work yet to be completed and documentary, regulatory and contractual closeout requirements yet to be met.
Substantial Completion Specifics	■ Submit written notice that the project is substantially complete ■ Provide a detailed punch list of items not yet in conformance with the contract documents;

- Submit preliminary copies of the operation and maintenance manuals,
- Submit the as-built drawings,
- Submit warranties, workmanship/maintenance bonds, maintenance agreements, final certifications, and similar documents,
- Obtain and submit releases enabling owner's full unrestricted use of the work and access to services and utilities, including occupancy permits, operating certifications, and similar releases,
- The contractor shall have completed all commissioning requirements in Division 17 except functional performance testing of systems,
- The contractor shall have completed all training required for owner's staff (since the owner now assumes responsibility for operation of the facility),
- Submit a letter to the architect requesting inspection and the Certificate of Substantial Completion, which will be signed and submitted to the owner.

Functional Completion

A defined point in time, in calendar days, after substantial completion wherein all remaining balancing and commissioning responsibilities of the contractor must be completed; with another (reduced) liquidated damages amount included.

Functional Completion Specifics

- The contractor shall submit commissioning acceptance procedures test check-off sheets, signed by the commissioning authority, and the commissioning authority's letter recommending Functional Completion,
- The commissioning authority will submit a final commissioning report recommending Functional Completion when all Division 17 requirements have been met and when the test engineer's final report is accepted by the commissioning authority.

Final Completion

Final completion occurs when the work is fully and finally completed in accordance with the contract documents and all deficiencies have been corrected.

Final Completion Specifics

- Submit "Consent of Surety to Final Payment." This letter is to be completed by the surety and mailed to the owner;
- Submit final payment request with final releases and supporting documentation not previously submitted or accepted;
- Submit a copy of the architect's final punch list of itemized work to be completed or corrected, stating that each item is complete (or otherwise resolved) for acceptance; endorsed and dated by the architect;
- Deliver tools, spare parts, extra stock of materials, and similar physical items to the owner;
- Make the final change-over of locks and transmit the new keys to the owner. Advise owner's personnel regarding change-over in security provisions;
- Discontinue and remove from the project site temporary facilities and services, along with construction tools and facilities, mock-ups, and similar elements;
- Complete final cleaning requirements, including touch-up of marred surfaces, and repair, restore, and touch-up exposed finishes;
- Submit a letter to the architect requesting inspection and the Certificate of Final Acceptance, which will be signed and submitted to the owner.

Final Acceptance Final acceptance is the written acceptance issued to the contractor by the owner after the contractor has achieved final completion.

❖ About The Appendices

Guide Specifications

There are approximately fifteen different guide specifications for reference and use by readers. One will note that there is an "l" series and an "s" series for specifications 01650, 15995, and 16995. This is done to indicate the adjustments one must consider when developing specifications for large ("l") projects requiring the prime contractor to engage a test engineer or small ("s") projects wherein a test engineer will not be required but many commissioning activities are still the responsibility of the contractors.

The Division 17 specification sections tend to be lengthy and include what appears to be redundancy. The fact is, commissioning is a detail intensive process which requires detail intensive specifications in order for all parties participating in the project to fully and thoroughly understand the requirements for commissioning. Because many owners and design teams are not familiar with the requirement for this level of detail, it would be misleading if this document did not make such requirements eminently clear. Section 17510, Commissioning Supply Air Systems is an excellent case in point. The common denominators to all units/systems to be tested are: 1) System/Equipment to be Tested, 2) Functions to be Tested, 3) Conditions of the Test, and 4) Acceptable Results.

These elements are repeated for each test to be performed, but are uniquely stated for each situation. There is no shortcut for imparting these requirements. If one is going to do commissioning, one must recognize the detail required to do so successfully.

Appendix 3-1

ATTACHMENT B

DOCUMENT REVIEW REQUIREMENTS

This Attachment lists the items to be provided by the Architect in accordance with Article II, Basic Services of the Architect, in the Conditions of Agreement. This list is not all inclusive nor is it limited to any items referred to or implied in other parts of the Agreement or normally provided under Article II of the Conditions of the Agreement. Items listed shall be included as Basic Services as fully as if individually listed in Article II.

ITEM	SCHEMATIC PHASE	DESIGN DEVELOPMENT PHASE	CONSTRUCTION DOCUMENT PHASE
Specification	System & material narrative description	Outline specification	Complete specification
CADD electronic files	Samples of CADD files from all project consultants	Samples of CADD files corrected to meet UW standards	Complete & accurate CADD files (all drawings)
Site	Existing conditions Site footprint Site entrance Demolition Site utilities Utility requirements Roads & driveways Loading dock location Future expansion Walkway locations Stairway locations Parking locations Waste collection locations	Pedestrian circulation Utility details Dimensions Traffic flow plan Handicapped flow plan Lighting plan Stairway connections Waste Containers Bicycle facilities Site drainage	Pipe sizes Connection details Contractor parking Construction area Construction phasing Site development phasing Street use plan
Landscaping	Existing conditions Existing irrigation Irrigation legend	Irrigation plan Planting plan	Soil preparation & planting specifications Guying details Piping diagrams Pipe sizes Design calculations Existing tree protection

ITEM	SCHEMATIC PHASE	DESIGN DEVELOPMENT PHASE	CONSTRUCTION DOCUMENT PHASE
Building Exterior Envelope	Typical elevations Building cross-sections Fenestration layout Material designations Energy code requirements Roof layout	Typical wall sections Typical window details Exterior door details Roof & drainage plan Parapet & coping details	Roof details Exterior details Roof mounted equipment Flashing details
Structural	Structural scheme Written description including seismic analysis of existing bldg & proposed strenghening techniques Structural legend	Structural sections Typical floor framing plan Main member sizing Foundation Plan	Structural details Foundation details Beam & column schedules Structural notes Calculations
Building Interior	Typical floor plans (min. 1/16" scale) Area use identification & area in sq. Ft. Janitor closet(s) location(s) Circulation paths Preliminary layouts of major lab spaces Show flexibility for expansion and alterations All room numbers Area tabulations compared to program requirements Cost study: existing, area separation, etc. Mechanical, electrical and other service closets and rooms	All floor plans (min. 1/16" scale) Wall types, fire ratings, smoke control zones Partition types Defined seating, serving & kitchen facilities Fixed seating Equipment & furniture layouts	Dimensioned floor plans Finish schedules Door & hardware schedules Interior elevations Reflected ceiling plans Partition details Interior details

ITEM	SCHEMATIC PHASE	DESIGN DEVELOPMENT PHASE	CONSTRUCTION DOCUMENT PHASE
Elevators	Elevator location(s) Equipment room location(s) Elevator legend	Elevator shaft section Equipment description	Dimensioned plans Complete specification Door & frame details Interior details with lighting
Plumbing & Piping	Location of headers Location of pipe chases Fixture locations Mechanical legend	Water header diagram Central cooling water header diagram Steam header diagram Piping plans	Pipe sizes Radiation riser diagram Plumbing riser diagram Water header diagram Central cooling water riser diagram Chilled water riser diagram Coil piping detail Convector piping detail Water heater piping detail Design calculations
HVAC	Identify all systems One-line flow diagrams Energy code requirements Special occupancy zones Mechanical legend Air intake & discharge locations	Preliminary calculations One-line duct layout Equipment list Equipment locations Control diagram Sequence of operation M/E smoke control scheme (matrix)	Equipment details Installation details Cross sections Connection to FA & MCC Design calculations
Fire Protection (Mechanical)	Connection to utility Location of sprinkler valve Sprinkler legend	Riser diagram One-line layout	Complete specifications Sprinkler valve details Header & piping layouts Pipe sizes Design calculations

ITEM	SCHEMATIC PHASE	DESIGN DEVELOPMENT PHASE	CONSTRUCTION DOCUMENT PHASE
Lighting	Zones w/foot-candles Fixture types Energy code requirements	Fixture/switching layout Light level calculations	Fixture schedule Installation details Control diagram Design calculations
Electric Power Distribution	One-line diagrams Electric vault location Electric closet(s) location(s) Electric legend	Equipment layout/sizes Panel locations/ schedules Power riser diagram Load estimate	Load summary Panel schedules Connection to FA & HVAC MCC details Design calculations
Fire Alarm	Connection to utility Panel location	Fire alarm zones Smoke zones Device locations Riser diagram	Connection details Connection to FA & HVAC Riser diagram
Telecommunications	Building & local distribution Frame closet locations & size Cable tray outlet	Riser diagrams Material cut-sheets Conduit plans Voice/data utility outlet locations	Backboard layout & connection diagrams Connection details Cable schedule
Service Facilities	Loading dock Service elevator Service road	Waste containers Recycle holding area Bottled gas area Any special waste handling Service vehicle parking area	Details for all accessory & support apparatus in each area
Handicapped Provisions	Access locations Restrooms	Ramped accesses	Details for all assocciated accessories & provisions
Personal Safety Provisions	Design considerations leading to an inherently safe occupancy environment	Any special systems or applications promoting personal safety	Details required for personal safety provisions

ITEM	SCHEMATIC PHASE	DESIGN DEVELOPMENT PHASE	CONSTRUCTION DOCUMENT PHASE
Commissioning		Documentation of design criteria and assumptions One-line diagrams Calculations System zoning Sequences of operation All data required in the FDI Manual, Volume 1	Production of the document required in the FDI Manual, Volume 1 Preparation of the contract documents in accordance with the requirement of the FDI Manual, Volume 1

END OF SECTION

Appendix 3-2

COMMISSIONING RELATED EXCERPTS FROM CSI FORMAT

Division 2 - Sitework
- 02600 Utility Piping
- 02660 Water Distribution
- 02680 Fuel and Steam Distribution
- 02700 Sewerage and Drainage
- 02780 Power and Communications
- 02810 Irrigation Systems

Division 3 - Doors and Windows
- 08300 Special Doors
- 08320 Security Doors
- 08740 Electro-Mechanical Hardware

Division 10 - Specialties
- 10410 Directories (Electronic)
- 10430 Exterior Signs (Electronic)

Division 11 - Equipment
- 11020 Security and Vault Equipment
- 11150 Parking Control Equipment
- 11160 Loading Dock Equipment
- 11190 Detention Equipment
- 11200 Water Supply Equipment
  - pumps, mixers, chemical feed, softening, disinfectant, fluoridation
- 11280 Hydraulic Gates and Valves
- 11300 Fluid Waste Treatment and Disposal Equipment
- 11400 Food Service Equipment
- 11700 Medical Equipment
  - sterilizing, dental, operating room, radiology

Division 13 - Special Construction
- 13030 Special Purpose Rooms
  - clean rooms, cold storage rooms, vaults
- 13150 Aquatic Facilities
  - swimming pools, aquariums
- 13200 Liquid and Gas Storage Tanks
- 13300 Utility Control Systems
- 13400 Industrial and Process Control Systems

Division 14 - Conveying Systems
- 14100 Dumb Waiters
- 14200 Elevators
- 14300 Escalators
- 14500 Material Handling Systems
- 14600 Hoists and Cranes

Division 15 - Mechanical
- 15450 Plumbing Equipment
- 15475 Pool and Fountain Equipment
- 15480 Special Equipment and Systems
  - compressed gas, deionized water, vacuum, fuel oil
- 15500 Heating, Ventilating, and Air Conditioning
  - hydronic, steam and condensate, refrigeration, pumps, water treatment
- 15550 Heat Generation
  - boilers, feedwater, fuel handling, furnaces
- 15650 Refrigeration
  - compressors, condensing units, chillers, cooling towers
- 15750 Heat Transfer
  - heat exchangers, heat pumps, packaged air conditioning, humidifiers, terminal units
- 15850 Air Handling
- 15950 Controls

Division 16 - Electrical
- 16200 Generators
- 16300 Medium Voltage Distribution
  - substations, transformers, switchboards, circuit breakers, interrupter switches, grounding
- 16400 Service and Distribution
  - voltage regulators, switchboards, metering, peak load controllers, transformers, panelboards, overcurrent protective devices, motor control, contactors
- 16600 Special Systems
  - uninteruptible power supply, engine generator, battery power
- 16720 Alarm and Detection Systems
  - fire alarm, gas detection, intrusion detection, security access
- 16740 Voice and Data Systems
- 16770 Public Address and Music Systems
- 16780 Television Systems
- 16850 Electric Resistance Heat
- 16900 Controls
  - Lighting, environmental systems control, building systems
- 16950 Testing

END OF SECTION

Appendix 4-1L

SECTION 01650 - GENERAL, FACILITY STARTUP/COMMISSIONING

GUIDE SPECIFICATION

The following guide specification is intended to be modified and included in the construction contract documents. Items to be modified will be decided by consultation involving the owner's project manager and the A/E. The A/E is expected to modify this and other specifications as necessary to accurately reflect commissioning requirements based upon specific systems, conditions, and requirements of the project.

PART 1 - GENERAL

1.1 SCOPE OF THE WORK

A. The intent of this section is to require the Contractor to provide qualified testing expertise to organize, schedule, coordinate and perform functional performance testing as outlined in Division 17.

B. Provide the services of a Test Engineer qualified in planning and performing testing, and troubleshooting equipment and systems, as described in these specifications.

1.2 RELATED WORK

A. Divisions 14, 15, 16, and 17 sections requiring functional performance testing.

1.3 RESPONSIBILITIES

A. The Test Engineer shall:

1. Review and approve all functional performance tests, results, and documentation required by the contract documents; for all equipment and systems; as performed by subcontractors, vendors, etc.;
2. Develop schedules for all testing; integrate testing into the master construction activity schedule; and coordinate all subcontractor testing as required;
3. Develop test procedures and forms for documentation of all equipment tests, system functional tests, and cross system functional tests. Test procedures shall be in accordance with equipment manufacturer's recommendations, where applicable. Test procedures shall fully describe system configuration and steps required for each test; appropriately documented so that another party can repeat the tests with virtually identical results;

4. Submit test procedure schedule, procedures, forms, and other documentation to the Commissioning Agent and Owner for approval six months prior to starting any testing required by Division 17;

5. Coordinate directly with each subcontractor on the project specific to their responsibilities and contractual obligations;

6. Provide qualified personnel for participation in commissioning tests, including seasonal testing required after the initial commissioning;

7. Provide engineering and technical expertise to oversee and direct the correction of deficiencies found during the commissioning process;

8. Observe the start-up and initial testing of equipment by the Contractor and subcontractors; and then all final tests of equipment and systems;

9. Manage all cross system testing such as HVAC, building automation, fire alarm, emergency power, life safety, elevators, etc.;

10. Note any inconsistencies or deficiencies in system operations and enforce system compliance or recommend to the Architect modifications to system design which will enhance system performance;

11. Coordinate the required A/E, Commissioning Agent, and Owner testing participation and approval procedures, after verifying that pretests have been satisfactorily conducted and final tests are ready to be performed;

12. In the event that a functional test fails, the cause of failure shall be determined and rectified as soon as possible, and then retested. If more than three functional tests of the same system(s) are required, the Contractor shall reimburse all associated costs for the extraordinary participation of the A/E, Commissioning Agent, and Owner's staff, as required by the particular test being performed;

13. Review operation and maintenance information and as-built drawings provided by the various subcontractors and vendors for verification, organization, and distribution;

14. Obtain all documentation from tests and assemble a final test report to be submitted to the Architect and the Commissioning Agent for approval.

15. Oversee and/or provide training for the systems specified in the Division with coordination by the Divisions 15 and 16 subcontractors.

1.4 TEST ENGINEER QUALIFICATIONS

A. The Test Engineer shall satisfy the following requirements:

1. Have extensive experience in startup and troubleshooting HVAC, hot water heating, chilled water, steam, plumbing, electrical, emergency power, fire alarm, life safety, laboratory and medical services systems of similar complexity to those contained in these documents;

2. Have excellent working knowledge of complex environmental, fire alarm, and electric power control and facility management systems; be capable of understanding control vendors' operating system and control code; be capable of trouble-shooting control code and recommending necessary modifications;

3. Be competent in system design and intent;

4. Be knowledgeable in test and balance of both air and hydronic systems;

5. Have excellent communication and writing skills, be highly organized, and be able to work well with both management and trades contractors.

B. A Bachelors degree in Mechanical Engineering and P.E. certification, with extensive practical field experience, is preferred; however, other technical training and experience with extensive practical field experience will be considered.

C. The Contractor shall submit the Test Engineer (TE) resume and sample documents to the A/E for approval; which shall include the following:

1. Education and technical training.

2. Present employment:

   a. Company name and address
   b. Present title and job description
   c. History of employment (include dates and positions held)

3. Relevant work experience:

   a. Job name
   b. Position held
   c. Work history (include dates and positions held)

4. Example of prior building commissioning project performed by the proposed TE:

   a. Submitted project shall be similar in commissioning scope and complexity
   b. Include construction/commissioning schedule developed by proposed TE
   c. Include test procedures developed by proposed TE
   d. Include final report prepared by proposed TE

D. Qualified Test Engineers may be available from (but are not limited to) the following firms:

1. (name to be entered)
2. (name to be entered)
3. (name to be entered)
4. or Owner approved equal

E. The Test Engineer cannot be financially associated with any of the Division 1 through 16 contractors or vendors prior to engaging in this contract, to avoid potential conflicts of interest.

F. The A/E reserves the right to personally interview the Test Engineer candidate prior to accepting placement in the position. Final approval of the Test Engineer will be by the A/E.

1.5 COMMISSIONING AGENT

A. The Owner will either hire a Commissioning Agent or appoint a staff engineer to act as Commissioning Agent to work with the Test Engineer in the development and execution of the commissioning program.

B. The duties of the Commissioning Agent are:

1. Review the Contractor's systems start-up plans;

2. Review the Contractor's equipment and component test procedures;

3. Review the Contractor's systems and inter-systems functional performance test procedures;

4. Witness, verify and approve satisfactory completion of equipment and component tests and systems and inter-systems functional performance tests;

5. Review and approve specified documentation;

6. When testing, adjusting and balancing (TAB) work is contracted separately by the Owner, coordinate the TAB firm's participation in the project;

7. Coordinate participation of Owner's personnel involved with equipment, component and systems performance verification and participation in required training; and

8. When commissioning has been successfully completed, recommend final acceptance to the Owner.

C. The Commissioning Agent is expected to communicate as follows:

1. The Commissioning Agent will formally communicate with the Contractor via approved project channels. It is expected, however, that informal communication and coordination will be conducted directly with the Test Engineer. As the Owner's commissioning representative, it is expected that the Commissioning Agent will communicate directly with consultants , as may be appropriate.

2. The Commissioning Agent will keep the Owner advised regarding commissioning activities, progress, problems which may develop, solutions to problems, systems performance, and schedules.

PART 2 - PRODUCTS

Not applicable.

PART 3 - EXECUTION

Not applicable.

END OF SECTION

Appendix 4-2L

SECTION 15995- MECHANICAL, FACILITY STARTUP/COMMISSIONING

GUIDE SPECIFICATION

The following guide specification is intended to be modified and included in the construction contract documents. Items to be modified will be decided by consultation involving the owner's project manager and the A/E. The A/E is expected to modify this and other specifications as necessary to accurately reflect commissioning requirements based upon specific systems, conditions, and requirements of the project.

PART 1 - GENERAL

1.1 SCOPE OF THE WORK

A. The purpose of this section is to specify Division 15 responsibilities and participation in the commissioning process.

B. Commissioning is the responsibility of the Contractor (including subcontractors and vendors). The Contractor is responsible to provide a Test Engineer to commission the facilities and provide all support required for start-up, testing, and commissioning (see Section 01650). Division 17 is intended to provide an indication of the tests which must be performed by the Contractor prior to verification by the Owner's Representative and the Commissioning Agent. The commissioning process requires Division 15 participation to ensure all portions of the work have been completed in a satisfactory and fully operational manner.

C. Work of Division 15 includes:

1. Start-up and testing of the equipment.

2. Assistance in testing, adjusting and balancing.

3. Operating equipment and systems as required for commissioning tests.

4. Providing qualified personnel for participation in commissioning test, including seasonal testing required after the initial commissioning.

5. Providing equipment, materials, and labor necessary to correct deficiencies found during the commissioning process which fulfill contract and warranty requirements.

6. Providing operation and maintenance information and as-built drawings to the Test Engineer for verification, organization, and distribution.

7. Providing assistance to the Test Engineer to develop and edit system operation descriptions.

8. Providing training for the systems specified in this Division with coordination by the Test Engineer, Owner's Representative and Commissioning Agent.

1.2 RELATED WORK

A. All start-up and testing procedures and documentation requirements specified within Division 15.

B. All Division 17 commissioning procedures that require participation of Division 15.

17400 - Commissioning: Plumbing Systems
17410 - Commissioning: High Purity Water Systems
17415 - Commissioning: High Purity Gas Systems
17420 - Commissioning: Laboratory Gas Systems
17430 - Commissioning: Process Chilled Water Systems
17500 - Commissioning: Heating, Ventilating and Air Conditioning Systems
17510 - Commissioning: Supply Air Systems
17520 - Commissioning: Exhaust Air Systems
17530 - Commissioning: Hot Water Heating Systems
17540 - Commissioning: Central Cooling Water Systems
17550 - Commissioning: Steam and Condensate Systems
17560 - Commissioning: Hydronic Heat Pump
17590 - Commissioning: Environmental Control Systems
17591 - Commissioning: Vibration Isolation
17595 - Commissioning: Testing, Adjusting and Balancing
17810 - Commissioning: Fire Protection/Suppression Systems

C. Cooperate with the test, adjust and balance (TAB) firm in the following manner:

1. Allow sufficient time before final commissioning dates so that testing, adjusting and balancing can be accomplished.

2. Put all heating, ventilating, and air conditioning equipment and systems into full operation and continue the operation during each working day of testing, adjusting and balancing and commissioning.

3. Provide labor and material to make corrections when required, without undue delay.

4. Include the cost of exchange sheaves and belts as may be required by the TAB firm.

5. Provide test holes in ducts and plenums where directed or necessary for pitot tubes to take air measurements and to balance the air systems. Test holes shall be provided with an approved removable plug or seal. At each location where ducts or plenums are insulated, test holes shall be provided with an approved extension with plug fitting.

6. Provide pressure and temperature taps as indicated on construction documents in locations as required by the TAB firm to adequately test and/or balance the hydronic systems.

PART 2 - PRODUCTS

2.1 TEST EQUIPMENT

A. Provide test equipment as necessary for start-up and commissioning of the mechanical equipment and systems. The TAB firm will provide the test equipment required to perform their service.

2.2 TEST EQUIPMENT - PROPRIETARY

A. Proprietary test equipment required by the manufacturer, whether specified or not, shall be provided by the manufacturer of the equipment. Manufacturer shall provide the test equipment, demonstrate its use, and assist the Test Engineer in the commissioning process. Proprietary test equipment shall become the property of the Owner upon completion of commissioning.

B. Identify the proprietary test equipment required in the test procedures submittals and in a separate list of equipment to be included in the operations and maintenance manuals.

PART 3 - EXECUTION

3.1 WORK PRIOR TO COMMISSIONING

A. Complete all phases of work so the system can be started, tested, adjusted, balanced, and otherwise commissioned. Division 15 has primary start-up responsibilities with obligations to complete systems, including all sub-systems so they are fully functional. This includes the complete installation of all equipment, materials, pipe, duct, wire, insulation, controls, etc., per the contract documents and related directives, clarifications, change orders, etc.

B. A commissioning plan will be developed by the Test Engineer and approved by the Commissioning Agent. Division 15 is obligated to assist the Test Engineer in preparing the commissioning plan by providing all necessary information pertaining to the actual equipment and installation. If system modifications/clarifications are in the contractual requirements of this and related sections of work, they will be made at no additional cost to the Owner. If Contractor initiated system changes have been made that alter the commissioning process, the Test Engineer will notify the Commissioning Agent and Owner's Representative for approval.

C. Specific pre-commissioning responsibilities of Division 15 are as follows:

1. Factory start-up services for the following items of equipment:

   a. Air-handling equipment
   b. Heating equipment
   c. Cooling equipment
   d. Plumbing equipment
   e. Special purpose equipment
   f. Pumps
   g. Chillers
   h. Cooling towers
   I. Variable speed drives

2. Normal start-up services required to bring each system into a fully operational state. This includes cleaning, filling, purging, leak testing, motor rotation check, control sequences of operation, full and part load performance, etc. The TAB firm will not begin the TAB work until each system is complete, including normal contractor start-up. The Test Engineer will not begin the commissioning process until each system is complete, including normal contractor start-up and the TAB work has been completed.

D. Commissioning is intended to begin upon completion of a system. Commissioning may proceed prior to the completion of systems, or sub-systems, and will be coordinated with the Test Engineer. Start of commissioning before system completion will not relieve Division 15 from completing those systems as per the schedule.

3.2 PARTICIPATION IN COMMISSIONING

A. Provide skilled technicians to start up all systems within Division 15. These same technicians shall be made available to assist the Test Engineer and Commissioning Agent in completing the commissioning program as it relates to each system and their technical specialty. Work schedules, time required for testing, etc., will be requested and coordinated by the Test Engineer. Division 15 will ensure that the qualified technician(s) are available and present during the agreed upon schedules and for sufficient duration to complete the necessary tests, adjustment, and/or problem resolutions.

B. System problems and discrepancies may require additional technician time, Test Engineer time, Commissioning Agent time, redesign and/or reconstruction of systems and system components. The additional technician time shall be made available for the subsequent commissioning periods until the required system performance is obtained.

C. The Owner's Representative and Commissioning Agent reserve the right to judge the appropriateness and qualifications of the technicians relative to each item of equipment or system. Qualifications of technicians include expert knowledge relative to the specific equipment involved, adequate documentation and tools to service/commission the equipment, and an attitude/willingness to work with the Test Engineer to get the job done.

3.3 WORK TO RESOLVE DEFICIENCIES

A. In some systems, misadjustments, misapplied equipment and/or deficient performance under varying loads will result in additional work being required to commission the systems. This work will be completed under the direction of the Architect and Owner's Representative, with input from the Contractor, equipment supplier, Test Engineer, and Commissioning Agent. Whereas all members will have input and the opportunity to discuss the work and resolve problems, the Architect will have final jurisdiction on the necessary work to be done to achieve performance.

B. Corrective work shall be completed in a timely fashion to permit timely completion of the commissioning process. Experimentation to render system performance will be permitted. If the Commissioning Agent deems the experimentation work to be ineffective or untimely as it relates to the commissioning process, the Commissioning Agent will notify the Owner indicating the nature of the problem, expected steps to be taken, and the deadline for completion of activities. If deadlines pass without resolution of the problem, the Owner reserves the right to obtain supplementary services and/or equipment to resolve the problem. Costs incurred to solve the problems in an expeditious manner will be the Contractor's responsibility.

3.4 SEASONAL COMMISSIONING AND OCCUPANCY VARIATIONS

A. Seasonal commissioning pertains to testing under full-load conditions during peak heating and peak cooling seasons, as well as part-load conditions in the spring and fall. Initial commissioning will be done as soon as contract work is completed regardless of season. Subsequent commissioning may be undertaken at any time thereafter to ascertain adequate performance during the different seasons.

B. All equipment and systems will be tested and commissioned in a peak season to observe full-load performance. Heating equipment will be tested during winter design extremes. Cooling equipment will be tested during summer design extremes, with a fully occupied building. Each Contractor and supplier will be responsible to participate in the initial and the alternate peak season test of the systems required to demonstrate performance; as scheduled by the Test Engineer, with three day (minimum) advance notification.

C. Subsequent commissioning may be required under conditions of minimum and/or maximum occupancy or use. All equipment and systems effected by occupancy variations will be tested and commissioned at the minimum and peak loads to observe system performance. The Contractor will be responsible to participate in the occupancy sensitive testing of systems to provide verification of adequate performance.

3.5 RECOMMISSIONING

A. After the initial and peak season commissioning is completed, there may be addition work required to serve new or revised loads. This work is not part of the contract.

3.6 TRAINING

A. Participate in the training of the Owner's engineering and maintenance staff, as required in Divisions 1 and 17, on each system and related components. Training, in part, will be conducted in a classroom setting, with system and component documentation, and suitable classroom training aids.

B. Training will be conducted jointly by the Test Engineer, Commissioning Agent, Owner's Representative, the design engineers, the Contractor, and the equipment vendors. The Test Engineer will be responsible for highlighting system peculiarities specific to this project.

3.7 SYSTEMS DOCUMENTATION

A. In addition to the requirements of Division 1, update contract documents to incorporate field changes and revisions to system designs to account for actual constructed configurations. All drawings shall be red-lined on two sets. Division 15 as-built drawings shall include architectural floor plans, elevations and details, and the individual mechanical or electrical systems in relation to actual building layout.

B. Maintain as-built red-lines as required by Division 1. Given the size and complexity of this project, red-line drawings at completion of construction, based on memory of key personnel, is not satisfactory. Continuous and regular red-lining of drawings is considered essential and mandatory.

3.8 MISCELLANEOUS SUPPORT

A. Division 15 shall remove and replace covers of mechanical equipment, open access panels, etc., to permit Contractor, Architect and Owner's Representative to observe equipment and controllers provided. Furnish ladders and flashlights as necessary.

END OF SECTION

Appendix 4-3L

SECTION 16995 - ELECTRICAL, FACILITY STARTUP/COMMISSIONING

GUIDE SPECIFICATION

The following guide specification is intended to be modified and included in the construction contract documents. Items to be modified will be decided by consultation involving the owner's project manager and the A/E. The A/E is expected to modify this and other specifications as necessary to accurately reflect commissioning requirements based upon specific systems, conditions, and requirements of the project.

PART 1 - GENERAL

1.1 SCOPE OF THE WORK

A. The purpose of this section is to specify Division 16 responsibilities and participation in the commissioning process.

B. Commissioning is the joint responsibility of the Contractor (including subcontractors and vendors) and the Commissioning Agent (hired directly by the Owner). The Contractor is responsible to provide a Test Engineer to commission the facilities and provide all support required for start-up, testing, and commissioning (see Section 01450). Division 17 is intended to provide an indication of the tests which must be performed by the Contractor prior to verification by the Commissioning Agent. The commissioning process requires Division 16 participation to ensure all portions of the work have been completed in a satisfactory and fully operational manner.

C. Work of Division 16 includes:

1. Start-up and testing of the equipment.

2. Assistance in testing, adjusting and balancing.

3. Providing qualified personnel for participation in commissioning tests, including seasonal testing required after the initial commissioning.

4. Providing equipment, materials, and labor necessary to correct deficiencies found during the commissioning process which fulfill contract and warranty requirements.

5. Providing operation and maintenance information and as-built drawings to the Test Engineer for verification, organization, and distribution.

6. Providing assistance to the Test Engineer to develop and edit system operation descriptions.

7. Providing training for the systems specified in this Division with coordination by the Test Engineer and Commissioning Agent.

1.2 RELATED WORK

A. All testing and start-up procedures and documentation requirements specified within Division 16.

B. All Division 17 commissioning procedures that require participation of Division 16.

17100 Commissioning: General Requirements
17210 Commissioning: Underground and Site Electrical
17600 Commissioning: Electrical Systems
17605 Commissioning: Electrical Primary Voltage Systems
17680 Commissioning: Clock Systems
17690 Commissioning: Lighting Control Systems
17800 Commissioning: Life Safety Systems

C. Cooperate with the electrical testing company (ETC) in the following manner:

1. Allow sufficient time before final commissioning dates so that testing and adjusting can be accomplished.

2. Provide labor and material to make corrections when required, without undue delay.

PART 2 - PRODUCTS

2.1 TEST EQUIPMENT

A. The majority of the test equipment will be provided by the ETC firm as part of their service. Provide test equipment as necessary to assist in the start-up of the electrical systems, mechanical systems and to test electrical equipment.

2.2 TEST EQUIPMENT - PROPRIETARY

A. Proprietary test equipment required by the manufacturer, whether specified or not, shall be provided by the manufacturer of the equipment. Manufacturer shall provide the test equipment, demonstrate its use, and assist the Test Engineer and Commissioning Agent in the commissioning process. Proprietary test equipment shall become the property of the Owner upon completion of commissioning.

B. Identify the proprietary test equipment required in the test procedures submittals and in a separate list of equipment to be included in the operations and maintenance manuals.

PART 3 - EXECUTION

3.1 WORK PRIOR TO COMMISSIONING

A. Complete all phases of work so the system can be started, tested, balanced, and otherwise commissioned. Division 16 has primary start-up responsibilities with obligations to complete systems, including all sub-systems so they are fully functional. This includes the complete installation of all equipment, materials, conduit, wire, controls, etc., per the contract documents and related directives, clarifications, change orders, etc.

B. A commissioning plan will be developed by the Test Engineer and approved by the Commissioning Agent. Division 16 is obligated to assist the Test Engineer and Commissioning Agent in preparing the commissioning plan by providing all necessary information pertaining to the actual equipment and installation. If system modifications/clarifications are in the contractual requirements of this and related sections of work, they will be made at no additional cost to the Owner. If Contractor initiated system changes have been made that alter the commissioning process, the Test Engineer will notify the Commissioning Agent and Owner's Representative for approval.

C. Specific pre-commissioning responsibilities of Division 16 are as follows:

1. Factory start-up services for the following items of equipment:

    a. Transformers
    b. Primary switchgear and substations
    c. Secondary switchgear
    d. Automatic Transfer Switches
    e. Emergency power systems
    f. Electrical distribution systems
    g. Lighting control systems
    h. Fire alarm systems
    i. Security systems
    j. Clock systems
    k. Special laboratory electrical systems
    l. Variable frequency drives
    m. Uninteruptable Power Supply

2. Normal start-up services required to bring each system into a fully operational state. This includes cleaning, testing, motor rotation check, control sequences of operation, full and part load performance, etc. The Test Engineer will not begin the commissioning process until each system is complete, including normal contractor start-up.

D. Commissioning is intended to begin upon completion of a system. Commissioning may proceed prior to the completion of systems, or sub-systems, and will be coordinated with the Test Engineer. Start of commissioning before system completion will not relieve Division 16 from completing those systems as per the schedule.

3.2 PARTICIPATION IN COMMISSIONING

A. Provide skilled technicians to start up all systems within Division 16. These same technicians shall be made available to assist the Test Engineer and Commissioning Agent in completing the commissioning program as it relates to each system and their technical specialty. Work schedules, time required for testing, etc., will be requested and coordinated by the Test Engineer. Division 16 will ensure that the qualified technician(s) are available and present during the agreed upon schedules and for sufficient duration to complete the necessary tests, adjustment, and/or problem resolutions.

B. System problems and discrepancies may require additional technician time, Test Engineer time, Commissioning Agent time, redesign and/or reconstruction of systems and system components. The additional technician time shall be made available for the subsequent commissioning periods until the required system performance is obtained.

C. The Owner's Representative and Commissioning Agent reserve the right to judge the appropriateness and qualifications of the technicians relative to each item of equipment or system. Qualifications of technicians include expert knowledge relative to the specific equipment involved, adequate documentation and tools to service/commission the equipment, and an attitude/willingness to work with the Test Engineer to get the job done.

3.3 WORK TO RESOLVE DEFICIENCIES

A. In some systems, misadjustments, misapplied equipment and/or deficient performance under varying loads will result in additional work being required to commission the systems. This work will be completed under the direction of the Architect and Owner's Representative, with input from the Contractor, equipment supplier, Test Engineer, and Commissioning Agent. Whereas all members will have input and the opportunity to discuss the work and resolve problems, the Architect will have final jurisdiction on the necessary work to be done to achieve performance.

B. Corrective work shall be completed in a timely fashion to permit timely completion of the commissioning process. Experimentation to render system performance will be permitted. If the Commissioning Agent deems the experimentation work to be ineffective or untimely as it relates to the commissioning process, the Commissioning Agent will notify the Owner indicating the nature of the problem, expected steps to be taken, and the deadline for completion of activities. If deadlines pass without resolution of the problem, the Owner reserves the right to obtain supplementary services and/or equipment to resolve the problem. Costs incurred to solve the problems in an expeditious manner will be the Contractor's responsibility.

3.4 SEASONAL COMMISSIONING AND OCCUPANCY VARIATIONS

A. Seasonal commissioning pertains to testing under full load electrical conditions during peak heating and peak cooling seasons, as well as part load conditions in the spring and fall. Initial commissioning will be done as soon as contract work is completed regardless of season. Subsequent commissioning may be undertaken at any time thereafter to ascertain adequate performance during the different seasons.

B. All equipment and systems will be tested and commissioned in a peak season to observe full load performance. Heating equipment will be tested during winter design extremes. Cooling equipment will be tested during summer design extremes, with a fully occupied building. Each Contractor and supplier will be responsible to participate in the initial and the alternate peak season test of the systems required to demonstrate performance; as scheduled by the Test Engineer, with three day (minimum) advance notification.

C. Subsequent commissioning may be required under conditions of minimum and/or maximum occupancy or use. All equipment and systems effected by occupancy variations will be tested and commissioned at the minimum and peak loads to observe system performance. The Contractor will be responsible to participate in the occupancy sensitive testing of systems to provide verification of adequate performance.

3.5 RECOMMISSIONING

A. After the initial and peak season commissioning is completed, there may be additional work required to serve new or revised loads. This work is not part of the contract.

3.6 TRAINING

A. Participate in the training of Owner's engineering and maintenance staff, as required in Divisions 1 and 17, on each system and related components. Training, in part, will be conducted in a classroom setting, with system and component documentation, and suitable classroom training aids.

B. Training will be conducted jointly by the Test Engineer, Commissioning Agent, Owner's Representative, the design engineers, the Contractor, and the equipment vendors. The Test Engineer will be responsible for highlighting system peculiarities specific to this project.

3.7 SYSTEMS DOCUMENTATION

A. In addition to the requirements of Division 1, update contract documents to incorporate field changes and revisions to system designs to account for actual constructed configurations. All drawings shall be red-lined on two sets. Division 16 as-built drawings shall include architectural floor plans, elevations and details, and the individual mechanical or electrical systems in relation to actual building layout.

B. Maintain as-built red-lines as required in Division 1. Given the size and complexity of this project, red-line drawings at completion of construction, based on memory of key personnel, is not satisfactory. Continuous and regular red-lining of drawings is considered essential and mandatory.

3.8 MISCELLANEOUS SUPPORT

A. Division 16 shall remove and replace covers of mechanical equipment, open access panels, etc., to permit Contractor, Architect and Owner's Representative to observe equipment and controllers provided. Furnish ladders and flashlights as necessary.

END OF SECTION

Appendix 4-1S

SECTION 01650 - GENERAL, FACILITY STARTUP/COMMISSIONING

GUIDE SPECIFICATION

The following guide specification is intended to be modified and included in the construction contract documents. Items to be modified will be decided by consultation involving the owner's project manager and the A/E. The A/E is expected to modify this and other specifications as necessary to accurately reflect commissioning requirements based upon specific systems, conditions, and requirements of the project.

PART 1 - GENERAL

1.1 SCOPE OF THE WORK

A. The purpose of this section is to specify Contractor responsibilities and participation in the start-up and commissioning process.

B. Commissioning is the responsibility of the Contractor. The Contractor is responsible to provide all scheduling, coordination and support required for start-up, testing, and commissioning. Division 17 is intended to provide an indication of the tests which must be performed by the Contractor prior to and including verification by the Owner's Representative. The commissioning process requires Division 15 and Division 16 participation to ensure all portions of the work have been completed in a satisfactory and fully operational manner.

1.2 RELATED WORK

A. Divisions 14, 15, 16, and 17 sections requiring functional performance testing.

1.3 RESPONSIBILITIES

A. The Contractor shall:

1. Review and approve all functional performance tests, results, and documentation required by the contract documents; for all equipment and systems; as performed by subcontractors, vendors, etc.;

2. Develop schedules for all testing; integrate testing into the master construction activity schedule; and coordinate all subcontractor testing as required;

3. Develop test procedures and forms for documentation of all equipment tests, system functional tests, and cross system functional tests. Test procedures shall be in

accordance with equipment manufacturer's recommendations, where applicable. Test procedures shall fully describe system configuration and steps required for each test; appropriately documented so that another party can repeat the tests with virtually identical results;

4. Submit test procedure schedule, procedures, forms, and other documentation to the Architect and Owner's Representative for approval six months prior to starting any testing required by Division 17;

5. Coordinate directly with each subcontractor on the project specific to their responsibilities and contractual obligations;

6. Provide qualified personnel for participation in commissioning tests;

7. Provide technical expertise to oversee and direct the correction of deficiencies found during the commissioning process;

8. Observe the start-up and initial testing of equipment by subcontractors; and then all final tests of equipment and systems;

9. Manage all cross-system testing such as HVAC, building automation, fire alarm, emergency power, life safety, elevators, etc.;

10. Note any inconsistencies or deficiencies in system operations and enforce system compliance or recommend to the Architect modifications to system design which will enhance system performance;

11. Coordinate the required Architect and Owner's Representative testing participation and approval procedures, after verifying that pretests have been satisfactorily conducted and final tests are ready to be performed;

12. In the event that a functional performance test fails, the cause of failure shall be determined and rectified as soon as possible, and then retested. If more than two functional performance tests, involving witnessing by the Arhictect and/or Owner's staff, of the same system(s) are required, the Contractor shall reimburse all associated costs for the extraordinary participation of the Architect and Owner's staff, as required by the particular test being performed;

13. Review operation and maintenance information and as-built drawings provided by the various subcontractors and vendors for verification, organization, and distribution;

14. Obtain all documentation from tests and assemble a final test report to be submitted to the Architect and the Owner's Representative for approval;

15. Oversee and/or provide training for the systems specified in Divisions 1 through 17 with coordination by the Divisions 15 and 16 subcontractors.

B. The duties of the Owner's Representative are:

1. Review the Contractor's systems start-up plans;

2. Review the Contractor's equipment and component test procedures;

3. Review the Contractor's systems and inter-systems functional performance test procedures;

4. Witness, verify and approve satisfactory completion of equipment and component tests and systems and inter-systems functional performance tests;

5. Review and approve specified documentation;

6. When testing, adjusting and balancing (TAB) work is contracted separately by the Owner, coordinate the TAB firm's participation in the project;

7. Coordinate participation of Owner's personnel involved with equipment, component and systems performance verification and participation in required training; and

8. When commissioning has been successfully completed, recommend final acceptance to the Architect.

9. The Owner's Representative will be assisted by the Owner's commissioning engineer and other members of the Owners maintenance and operations staff. It is expected that informal communication, for coordination and technical concurrence, will occur between the commissioning engineer, Contractor and sub-contractors. Such communication is intended to facilitate the coordination and cooperation of participants in the commissioning process, but not affect the Contractor's responsibilities.

C. The Owner's Representative is expected to communicate as follows:

1. The Owner's Representative will formally communicate with the Contractor via approved project channels. It is expected, however, that informal communication and coordination will be conducted directly with the Contractor and sub-contractors. As

the Owner's commissioning representative, it is expected that the commissioning engineer will also communicate directly with consultants , as may be appropriate.

2. The Owner's Representative will keep the Architect and Owner advised regarding commissioning activities, progress, problems which may develop, solutions to problems, systems performance, and schedules.

PART 2 - PRODUCTS

Not applicable.

PART 3 - EXECUTION

Not applicable.

END OF SECTION

Appendix 4-2S

SECTION 15995 - MECHANICAL, FACILITY STARTUP/COMMISSIONING

GUIDE SPECIFICATION

The following guide specification is intended to be modified and included in the construction contract documents. Items to be modified will be decided by consultation involving the owner's project manager and the A/E. The A/E is expected to modify this and other specifications as necessary to accurately reflect commissioning requirements based upon specific systems, conditions, and requirements of the project.

PART 1 - GENERAL

1.1 SCOPE OF THE WORK

A. The purpose of this section is to specify Division 15 responsibilities and participation in the commissioning process.

B. Commissioning is the responsibility of the Contractor (including subcontractors and vendors). The Contractor is responsible to provide all scheduling, coordination and support required for start-up, testing, and commissioning (see Section 01650). Division 17 is intended to provide an indication of the tests which must be performed by the Contractor prior to and including verification by the Owner's Representative. The commissioning process requires Division 15 participation to ensure all portions of the work have been completed in a satisfactory and fully operational manner.

C. Work of Division 15 includes:

1. Start-up and testing of the mechanical equipment and systems.
2. Assistance in testing, adjusting and balancing.
3. Operating equipment and systems as required for commissioning tests.
4. Providing qualified personnel for participation in commissioning.
5. Providing equipment, materials, and labor necessary to correct deficiencies found during the commissioning process which fulfill contract and warranty requirements.
6. Providing operation and maintenance information and as-built drawings to the Contractor.

7. Providing assistance to the Contractor to develop and edit system operation descriptions.

8. Providing training for the systems specified in this Division with coordination by the Contractor and Owner's Representative.

1.2 RELATED WORK

A. All start-up and testing procedures and documentation requirements specified within Division 15.

B. All Division 17 commissioning procedures that require participation of Division 15.

C. Cooperate with the testing, adjusting and balancing (TAB) firm in the following manner:

1. Allow sufficient time before final commissioning dates so that testing, adjusting and balancing can be accomplished.

2. Put all heating, ventilating, and air conditioning equipment and systems into full operation and continue the operation during each working day of testing, adjusting and balancing and commissioning.

3. Provide labor and material to make corrections when required, without undue delay.

4. Include the cost of exchange sheaves and belts as may be required by the TAB firm.

5. Provide test holes in ducts and plenums where directed or necessary for pitot tubes to take air measurements and to balance the air systems. Test holes shall be provided with an approved removable plug or seal. At each location where ducts or plenums are insulated, test holes shall be provided with an approved extension with plug fitting.

6. Provide pressure and temperature taps as indicated on construction documents in locations as required by the TAB firm to adequately test and/or balance the hydronic systems.

PART 2 - PRODUCTS

2.1 TEST EQUIPMENT

A. Provide test equipment as necessary for start-up and commissioning of the mechanical equipment and systems. The TAB firm will provide the test equipment required to perform TAB services.

B. Proprietary test equipment required by the mechanical equipment manufacturer, whether specified or not, shall be provided by the manufacturer of the equipment. Manufacturer shall demonstrate its use and assist the Contractor in the commissioning process.

PART 3 - EXECUTION

3.1 WORK PRIOR TO COMMISSIONING

A. Complete all phases of work so each system can be started, tested, adjusted, balanced, and otherwise commissioned. Division 15 has primary start-up responsibilities with obligations to complete systems, including all sub-systems, so they are fully functional. This includes the complete installation of all equipment, materials, pipe, duct, wire, insulation, controls, etc., per the contract documents and related directives, clarifications, change orders, etc.

B. A commissioning plan will be developed by the Contractor and approved by the Owner's Representative. Division 15 is obligated to assist the Contractor in preparing the commissioning plan by providing all necessary information pertaining to the actual equipment and installation. If system modifications/clarifications are in the contractual requirements of this and related sections of work, they will be made at no additional cost to the Owner. If Contractor initiated system changes have been made that alter the commissioning process, the Contractor will notify the Owner's Representative for approval.

C. Specific pre-commissioning responsibilities of Division 15 are as follows:

1. Factory start-up services for the following items of equipment: Air-handling equipment, heating equipment, cooling equipment, plumbing equipment, pumps, chillers, cooling towers, variable speed drives.

2. Normal start-up services required to bring each system into a fully operational state. This includes cleaning, filling, purging, leak testing, alignment, lubrication, motor rotation check, control sequences of operation, full and part load performance, etc. The TAB firm will not begin the TAB work until each system is complete, including

normal contractor start-up. The Contractor will not begin the commissioning process until each system is complete, including normal contractor start-up, and the TAB work has been completed.

D. Commissioning is intended to begin upon completion of a system. Commissioning may proceed prior to the completion of systems, or sub-systems, and will be coordinated with the Contractor. Start of commissioning before system completion will not relieve Division 15 from completing those systems as per the schedule.

3.2 PARTICIPATION IN COMMISSIONING

A. Provide skilled technicians to start up all systems within Division 15. These same technicians shall be made available to assist the Contractor and Owner's Representative in completing the commissioning program as it relates to each system and their technical specialty. Work schedules, time required for testing, etc., will be requested and coordinated by the Contractor. Division 15 will ensure that qualified technician(s) are available and present during the agreed upon schedules and for sufficient duration to complete the necessary tests, adjustment, and/or problem resolutions.

B. System problems and discrepancies may require additional technician time. The additional technician time shall be made available for the subsequent commissioning periods until required system performance is obtained.

C. The Owner's Representative reserves the right to judge the appropriateness and qualifications of the technicians relative to each item of equipment or system. Qualifications for technicians include expert knowledge relative to the specific equipment involved, adequate documenta-tion and tools to service/commission the equipment, and an attitude/willingness to work with the Contractor to get the job done.

3.3 WORK TO RESOLVE DEFICIENCIES

A. In some systems, misadjustments, misapplied equipment and/or deficient performance under varying loads will result in additional work being required to commission the systems. This work will be completed under the direction of the Owner's Representative and the Architect, with input from the Contractor and equipment supplier. Whereas all members will have input and the opportunity to discuss the work and resolve problems, the Architect will have final jurisdiction on the necessary work to be done to achieve performance.

B. Corrective work shall be completed in a timely fashion to permit timely completion of the commissioning process. Experimentation to render system performance will be permitted. If the Architect deems the experimentation work to be ineffective or untimely as it relates to the commissioning process, the Architect will notify the Owner indicating the nature of the problem, expected steps to be taken, and the deadline for completion of activities. If deadlines pass without resolution of the problem, the Owner reserves the right to obtain supplementary services and/or equipment to resolve the problem. Costs incurred to solve the problems in an expeditious manner will be the Contractor's responsibility.

3.4 SEASONAL COMMISSIONING AND OCCUPANCY VARIATIONS

A. Seasonal commissioning pertains to testing under full-load conditions during peak heating and peak cooling seasons, as well as part-load conditions in the spring and fall. Initial commissioning will be done as soon as contract work is completed regardless of season. Commissioning under conditions representing other than the current season may be undertaken at a later time by the Owner's Representative, wherein the Contractor will not be expected to participate. Discrepancies discovered with the Contractor's equipment or workmanship will be handled as warranty items.

B. Commissioning may be required under conditions of minimum and/or maximum occupancy or use. All equipment and systems effected by occupancy variations will be tested and commissioned at the minimum and peak loads to observe system performance. The Contractor will be responsible to participate in the occupancy sensitive testing of systems to provide verification of adequate performance. If such occupancy is not available within the contract period, related commissioning may be undertaken at a later time by the Owner's Representative, wherein the Contractor will not be expected to participate. Discrepancies discovered with the Contractor's equipment or workmanship will be handled as warranty items.

3.5 RETESTING AND RECOMMISSIONING

A. Any fault in material or in any part of the installation revealed by commissioning tests shall be investigated, replaced or repaired by the Contractor and the same test repeated at the Contractor's expense until no fault appears.

B. After the initial and peak season commissioning is completed, there may be additional work required to serve new or revised loads. This work is not part of the contract.

3.6 TRAINING

A. Participate in the training of the Owner's engineering and maintenance staff, as required in Divisions 1 and 17, on each system and related components. Training, in part, will be conducted in a classroom setting, with system and component documentation, and suitable classroom training aids.

B. Training will be conducted jointly by the Contractor, the design engineers, and the equipment vendors. The Contractor will be responsible for highlighting system peculiarities specific to this project.

3.7 SYSTEMS DOCUMENTATION

A. In addition to the requirements of Division 1, update contract documents to incorporate field changes and revisions to system designs to account for actual constructed configurations. All drawings shall be red-lined on two sets. Division 15 as-built drawings shall include architectural floor plans, elevations and details, and the individual mechanical or electrical systems in relation to actual building layout.

B. Maintain as-built red-lines as required by Division 1. Red-lining drawings at completion of construction, based on memory of key personnel, is not satisfactory. Continuous and regular red-lining of drawings is considered essential and mandatory.

3.8 MISCELLANEOUS SUPPORT

A. Division 15 shall remove and replace covers of mechanical equipment, open access panels, etc., to permit Contractor, Architect and Owner's Representative to observe equipment and controllers provided. Furnish ladders and flashlights as necessary.

END OF SECTION

Appendix 4-3S

SECTION 16995 - ELECTRICAL, FACILITY STARTUP/COMMISSIONING

GUIDE SPECIFICATION

The following guide specification is intended to be modified and included in the construction contract documents. Items to be modified will be decided by consultation involving the owner's project manager and the A/E. The A/E is expected to modify this and other specifications as necessary to accurately reflect commissioning requirements based upon specific systems, conditions, and requirements of the project.

PART 1 - GENERAL

1.1 SCOPE OF THE WORK

A. The purpose of this section is to specify Division 16 responsibilities and participation in the commissioning process.

B. Commissioning is the responsibility of the Contractor (including subcontractors and vendors). The Contractor is responsible to provide all scheduling, coordination and support required for start-up, testing, and commissioning (see Section 01650). Division 17 is intended to provide an indication of the tests which must be performed by the Contractor prior to and including verification by the Owner's Representative. The commissioning process requires Division 16 participation to ensure all portions of the work have been completed in a satisfactory and fully operational manner.

C. Work of Division 16 includes:

1. Start-up and testing of the electrical equipment and systems.
2. Assistance in testing, adjusting and balancing.
3. Operating equipment and systems as required for commissioning tests.
4. Providing qualified personnel for participation in commissioning.
5. Providing equipment, materials, and labor necessary to correct deficiencies found during the commissioning process which fulfill contract and warranty requirements.
6. Providing operation and maintenance information and as-built drawings to the Contractor.

7. Providing assistance to the Contractor to develop and edit system operation descriptions.

8. Providing training for the systems specified in this Division with coordination by the Contractor and Owner's Representative.

1.2 RELATED WORK

A. All start-up and testing procedures and documentation requirements specified within Division 16.

B. All Division 17 commissioning procedures that require participation of Division 16.

C. Cooperate with the electrical testing company (ETC) in the following manner:

1. Allow sufficient time before final commissioning dates so that testing and adjusting can be accomplished.

2. Provide labor and material to make corrections when required, without undue delay.

PART 2 - PRODUCTS

2.1 TEST EQUIPMENT

A. Provide test equipment as necessary for start-up and commissioning of the electrical equipment and systems and, as may be necessary, to assist in the start-up of the mechanical systems.

B. Proprietary test equipment required by the electrical equipment manufacturer, whether specified or not, shall be provided by the manufacturer of the equipment. Manufacturer shall demonstrate its use and assist the Contractor in the commissioning process.

PART 3 - EXECUTION

3.1 WORK PRIOR TO COMMISSIONING

A. Complete all phases of work so each system can be started, tested, phase balanced, and otherwise commissioned. Division 16 has primary start-up responsibilities with obligations to complete systems, including all sub-systems, so they are fully functional. This includes the complete installation of all equipment, materials, conduit, wire, controls, etc., per the contract documents and related directives, clarifications, change orders, etc.

B. A commissioning plan will be developed by the Contractor and approved by the Owner's Representative. Division 16 is obligated to assist the Contractor in preparing the commissioning plan by providing all necessary information pertaining to the actual equipment and installation. If system modifications/clarifications are in the contractual requirements of this and related sections of work, they will be made at no additional cost to the Owner. If Contractor initiated system changes have been made that alter the commissioning process, the Contractor will notify the Owner's Representative for approval.

C. Specific pre-commissioning responsibilities of Division 16 are as follows:

1. Factory start-up services for the following items of equipment: Transformers, primary switchgear and substations, secondary switchgear, automatic transfer switches, electrical distribution systems, lighting control systems, fire alarm systems, variable speed drives.

2. Normal start-up services required to bring each system into a fully operational state. This includes cleaning, testing, motor rotation check, alignment, lubrication, control sequences of operation, full and part load performance, etc. The Contractor will not begin the commissioning process until each system is complete, including normal contractor start-up.

D. Commissioning is intended to begin upon completion of a system. Commissioning may proceed prior to the completion of systems, or sub-systems, and will be coordinated with the Contractor. Start of commissioning before system completion will not relieve Division 16 from completing those systems as per the schedule.

3.2 PARTICIPATION IN COMMISSIONING

A. Provide skilled technicians to start up all systems within Division 16. These same technicians shall be made available to assist the Contractor and Owner's Representative in completing the commissioning program as it relates to each system and their technical specialty. Work schedules, time required for testing, etc., will be requested and coordinated by the Contractor. Division 16 will ensure that qualified technician(s) are available and present during the agreed upon schedules and for sufficient duration to complete the necessary tests, adjustment, and/or problem resolutions.

B. System problems and discrepancies may require additional technician time. The additional technician time shall be made available for the subsequent commissioning periods until required system performance is obtained.

C. The Owner's Representative reserves the right to judge the appropriateness and qualifications of the technicians relative to each item of equipment or system. Qualifications for technicians include expert knowledge relative to the specific equipment involved, adequate documenta-tion and tools to service/commission the equipment, and an attitude/willingness to work with the Contractor to get the job done.

3.3 WORK TO RESOLVE DEFICIENCIES

A. In some systems, misadjustments, misapplied equipment and/or deficient performance under varying loads will result in additional work being required to commission the systems. This work will be completed under the direction of the Owner's Representative and the Architect, with input from the Contractor and equipment supplier. Whereas all members will have input and the opportunity to discuss the work and resolve problems, the Architect will have final jurisdiction on the necessary work to be done to achieve performance.

B. Corrective work shall be completed in a timely fashion to permit timely completion of the commissioning process. Experimentation to render system performance will be permitted. If the Architect deems the experimentation work to be ineffective or untimely as it relates to the commissioning process, the Architect will notify the Owner indicating the nature of the problem, expected steps to be taken, and the deadline for completion of activities. If deadlines pass without resolution of the problem, the Owner reserves the right to obtain supplementary services and/or equipment to resolve the problem. Costs incurred to solve the problems in an expeditious manner will be the Contractor's responsibility.

3.4 SEASONAL COMMISSIONING AND OCCUPANCY VARIATIONS

A. Seasonal commissioning pertains to testing under full-load electrical conditions during peak heating and peak cooling seasons, as well as part-load conditions in the spring and fall. Initial commissioning will be done as soon as contract work is completed regardless of season. Commissioning under conditions representing other than the current season may be undertaken at a later time by the Owner's Representative, wherein the Contractor will not be expected to participate. Discrepancies discovered with the Contractor's equipment or workmanship will be handled as warranty items.

B. Commissioning may be required under conditions of minimum and/or maximum occupancy or use. All equipment and systems effected by occupancy variations will be tested and commissioned at the minimum and peak loads to observe system performance. The Contractor will be responsible to participate in the occupancy sensitive testing of systems to provide verification of adequate performance. If such occupancy is not available within the contract period, related commissioning may be undertaken at a later time by the Owner's Representative, wherein the Contractor will not be expected to participate. Discrepancies discovered with the Contractor's equipment or workmanship will be handled as warranty items.

3.5 RETESTING AND RECOMMISSIONING

A. Any fault in material or in any part of the installation revealed by commissioning tests shall be investigated, replaced or repaired by the Contractor and the same test repeated at the Contractor's expense until no fault appears.

B. After the initial and peak season commissioning is completed, there may be additional work required to serve new or revised loads. This work is not part of the contract.

3.6 TRAINING

A. Participate in the training of the Owner's engineering and maintenance staff, as required in Divisions 1 and 17, on each system and related components. Training, in part, will be conducted in a classroom setting, with system and component documentation, and suitable classroom training aids.

B. Training will be conducted jointly by the Contractor, the design engineers, and the equipment vendors. The Contractor will be responsible for highlighting system peculiarities specific to this project.

3.7 SYSTEMS DOCUMENTATION

A. In addition to the requirements of Division 1, update contract documents to incorporate field changes and revisions to system designs to account for actual constructed configurations. All drawings shall be red-lined on two sets. Division 16 as-built drawings shall include architectural floor plans, elevations and details, and the individual electrical systems in relation to actual building layout.

B. Maintain as-built red-lines as required by Division 1. Red-lining drawings at completion of construction, based on memory of key personnel, is not satisfactory. Continuous and regular red-lining of drawings is considered essential and mandatory.

3.8 MISCELLANEOUS SUPPORT

A. Division 16 shall remove and replace covers of electrical equipment, open manholes, etc., to permit Contractor, Architect and Owner's Representative to observe equipment and wiring provided. Furnish ladders and flashlights as necessary.

END OF SECTION

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END OF SECTION

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SECTION 17100 - COMMISSIONING, GENERAL REQUIREMENTS

GUIDE SPECIFICATION

The following guide specification is intended to be modified and included in the construction contract documents. Items to be modified will be decided by consultation involving the owner's project manager and the A/E. The A/E is expected to modify this and other specifications as necessary to accurately reflect commissioning requirements based upon specific systems, conditions, and requirements of the project.

PART 1 - GENERAL

1.1 DESCRIPTION

A. Purpose

1. The purpose of the commissioning process is to provide the Owner assurance that systems have been installed in the prescribed manner and will operate within the performance guidelines. Commissioning is intended to enhance the quality of system start-up and aid in the orderly transfer of systems to beneficial use by the Owner.

2. The Contractor verifies installation, provides scheduling and coordination of commissioning activities, performs training, starts up equipment, conducts functional performance testing, corrects deficiencies, performs retests, and provides documentation of the process.

3. The Commissioning Agent, hired directly by the Owner, provides the Owner an unbiased, objective view of the systems; installation, documentation, operation, and performance.

4. Commissioning procedures and results will be observed by the Owner's designated witnesses (Commissioning Agent and/or Owner's staff). The Contractor is expected to verify the functional readiness of systems to be tested prior to performing the tests in the presence of the Owner's witness(es). A high rate of test failure will indicate that the Contractor has not adequately verified the readiness of the systems.

B. General

1. Furnish labor and material to accomplish building commissioning as specified herein.
2. Requirements of Division 17 shall be accomplished by a qualified Test Engineer, as specified in 01650.

3. The requirement for and responsibilities of the Test Engineer are indicated in Section 01650 and Division 17.
4. The Commissioning Agent is an independent contractor and will work under a separate contract directly with the Owner. The responsibilities of the Commissioning Agent are indicated, for information only, in Section 01650.
5. Unless noted otherwise, functional performance tests (FPT's) described under "Acceptance Criteria" in the various Sections of this Division, apply to all equipment and systems identified under "Systems / Equipment to be Tested:"

1.2 COORDINATION

A. Related Work

1. Refer to Sections 01650, 15995 and 16995 for additional contractor responsibilities relative to the commissioning process.

B. Coordination and Management: Provide overall coordination and management of the commissioning program as specified herein. The commissioning process will require cooperation of the Contractor, subcontractors, vendors, Architect, Commissioning Agent, and Owner. The commissioning team shall be comprised of the following.

1. Contractor
    a. Project Manager
    b. Test Engineer
2. Subcontractors
    a. As required by the Prime Contractor
3. Commissioning Agent
    a. Project Manager
    b. Project Engineers
4. Owner Representative(s)
5. Architect
    a. Architect
    b. Mechanical consultant
    c. Electrical consultant

1.3 SUBMITTALS

A. General: Submit the following in accordance with Conditions of the Contract and Division 1 Specification Sections.

B. Commissioning Plan: Submit commissioning plan to the Owner's Representative for review and approval by the Architect and Commissioning Agent within 90 calendar days of Notice to Proceed.

C. Commissioning Schedule: Submit commissioning schedule to the Owner's Representative for review and approval by the Architect and Commissioning Agent within 90 calendar days of Notice to Proceed.

D. Start-up Plan: For each piece of equipment or system for which formal start-up is specified elsewhere in this Division, submit to the Owner's Representative for review and approval by the Architect and Commissioning Agent. Obtain approval of the start-up plan prior to beginning start-up activities.

1. Start-up schedule
2. Names of firms/individuals required to participate
3. Detailed start-up procedures
4. Start-up data forms

E. Test Equipment Identification List: For each instrument, sorted according to intended use, submit to the Owner's Representative for review and approval by the Architect and Commissioning Agent:

1. Manufacturer
2. Model Number
3. Serial Number
4. Calibration certification
5. Range
6. Accuracy
7. Resolution
8. Intended use

F. Operations and Maintenance Manuals: Submit to Owner's Representative prior to the start of training.

G. Start-up Procedures: Submit start-up procedures for equipment for which formal start-up is specified elsewhere, to the Owner's Representative for review and approval by the Architect and Commissioning Agent. These procedures will be reviewed for technical depth, clarity of documentation, and completeness.

H. Start-up Data Forms: Submit start-up data forms for equipment for which formal start-up is specified elsewhere, to the Owner's Representative for review and approval by the Architect and Commissioning Agent.

I. Testing, Adjusting, and Balancing (TAB) Data Forms: Submit TAB data forms to the Owner's Representative for review and approval by the Architect and Commissioning Agent.

J. Testing, Adjusting, and Balancing (TAB) Procedures: Submit written TAB procedures to the Owner's Representative for review and approval by the Architect and Commissioning Agent.

K. Testing, Adjusting, and Balancing (TAB) Report: Submit written TAB report to the Owner's Representative for review and approval by the Architect and Commissioning Agent.

L. Functional Performance Test (FPT) Procedures: Submit FPT procedures for FPTs specified elsewhere, to the Owner's Representative for review and approval by the Architect and Commissioning Agent.

1. Each procedure shall have a unique alpha-numeric designator.
2. The same procedure may be applied to multiple identical pieces of equipment or systems.
3. Procedures shall reference the applicable specification section upon which the procedure is based..
4. Procedures will be reviewed for technical depth, clarity of documentation, compliance with "Acceptance Criteria" specified elsewhere, and completeness.
5. Identify the value for all setpoints and inputs, positions of adjustable devices, valves, dampers and switches.
6. Identify the range of acceptable results for each condition tested.
7. FPT procedures shall be detailed test instructions, written with sufficient step-by-step information to allow a test to be repeated under identical conditions with repeatable results.

M. Functional Performance Test (FPT) Data Forms: Submit FPT data forms for equipment for which FPTs are specified elsewhere, to the Owner's Representative for review and approval by the Architect and Commissioning Agent.

1. Identify each FPT test data form by a unique designator consisting of the applicable FPT procedure designator followed by a dash digit suffix to distinguish multiple repetitions of the same procedure.

2. Include space to record
    a. Description of the procedure
    b. Whether the form is for a retest of a failed procedure
    c. Identification and location of the equipment being tested
    d. Identification of instrumentation used, by serial number
    e. Observed conditions at each step of the procedure
    f. "Acceptable Results" as specified elsewhere
    g. Date of the test
    h. Names of technicians performing the procedure
    i. Name and signature of the Test Engineer
    j. Name and signature of the Commissioning Agent or Owner-designated witness. Signature of witness shall only indicate concurrence with reported results and observations. Acceptance of the results will be reported separately by the Commissioning Agent after review of the FPT data forms.

N. Functional Performance Test (FPT) Deficiency Report Forms: Submit FPT deficiency report forms to the Owner's Representative for review and approval by the Architect and Commissioning Agent. Include space to record

1. Associated FPT test data form number
2. Date of test
3. Name of person reporting the deficiency
4. Description of the observations associated with the failure of the test
5. Cause of the failure, if apparent at the time of the test
6. Date and description of corrective action taken
7. Name and signature of person taking corrective action
8. Schedule for retest

1.4 COMMISSIONING PLAN

Develop a commissioning plan to identify how commissioning activities will be integrated into general construction and trade activities. The plan is the key means for the Test Engineer to inform all parties as to how each system functions, independently and with respect to other systems. The plan shall be updated regularly and redistributed to the commissioning team for review and comment. The intent of this plan is to evoke questions, expose issues, and resolve them with input from the entire commissioning team early in construction. The commissioning plan shall identify how commissioning responsibilities are distributed.

A. Include an organizational chart showing lines of communication and authority of the Test Engineer relative to key General Contractor positions and to key subcontractors.

B. Identify who will be responsible for producing the various procedures, reports, Owner notifications and forms required in this Division.

C. Include the commissioning schedule.

D. Describe the test/acceptance procedure.

E. Identify which subcontractors will participate in each of the tests.

F. Identify instrumentation required for each test.

G. Identify who will provide instrumentation for each test.

H. Operational Description: This shall include, for example, the design criteria, design intent, code requirements, specifics of the equipment to be provided, sequences of operation, operating priorities, protocols, etc.

1.5 SCHEDULE

A. Commissioning Schedule: Integrate functional performance testing and commissioning requirements into the Critical Path Method (CPM) master construction schedule. Commissioning scheduling is the responsibility of the Contractor.

1. Prior to the beginning of start-up or functional performance testing activities, update the schedule of commissioning activities monthly.
2. Two weeks prior to the beginning of start-up or functional performance testing activities, provide a detailed two week look-ahead schedule. Thereafter, update the two week look-ahead schedule weekly for the duration of commissioning for that construction phase. The two week look-ahead schedule shall identify the date, time, beginning location, Contractor personnel required, and anticipated duration for each start-up or test activity.

B. Commissioning of systems shall proceed per the criteria established in the specific sections that follow, with activities to be performed on a timely basis. Commissioning of systems may proceed prior to final completion of systems. The Test Engineer must be available to respond promptly to avoid delay to the CPM schedule.

C. Problems observed shall be addressed immediately, in terms of notification to responsible parties, and actions to correct deficiencies.

1.6 COORDINATION WITH OWNER'S REPRESENTATIVE WITNESS

A. The Owner's Representative will witness all start-up and test activities specified in this Division. The Owner's Representative will designate witnesses and alternates for each activity.

B. Notify the Owner's Representative in writing of the date, time, location, and anticipated duration of start-up and test activities as required in "Schedule" above.

C. Provide written timely notice to Owner's Representative of any changes in date, time, location, or anticipated duration of start-up and test activities. For the purpose of this paragraph, written notice shall be received by Owner's Representative a minimum of 72 hours in advance to be considered timely notice.

D. Contractor shall reimburse Owner for actual costs incurred by the Owner as the result of failure to provide timely notice per preceding paragraph of changes in date, time, location, or anticipated duration of start-up and test activities.

E. Obtain the signature of designated witness on all data forms. If the witness is unavailable at the scheduled time and location of the activity, so note, and proceed per schedule without the witness.

1.7 COMMISSIONING MEETINGS

A. Initial commissioning meeting:

1. Within 60 days after the preconstruction meeting the Contractor shall schedule a meeting to review commissioning requirements and schedules for the project.
2. Attendance is required of the following: Contractor's superintendent and Test Engineer, mechanical subcontractor, electrical subcontractor, environmental control system/building automation system subcontractor, Architect, mechanical engineer, electrical engineer, Owner's Representative, Commissioning Agent, and others as may be appropriate.
3. The Test Engineer will preside and conduct the meeting; and will record, reproduce, and distribute copies of minutes within seven days thereafter to all meeting participants.
4. The purpose of the meeting is to introduce the key representatives of all parties directly involved with commissioning the building; to present and discuss the commissioning schedule; to identify construction completion requirements of the subcontractors which are "critical path" items in regard to each scheduled

commissioning activity; and to identify and resolve any uncertainties regarding process and responsibilities.

B. Commissioning progress meetings:

1. Attendance shall include the Test Engineer, mechanical subcontractor, electrical subcontractor, environmental control system/building automation system subcontractor, Owner's Representative, Commissioning Agent, and others as may be appropriate.
2. The Test Engineer will preside and conduct the meetings; and will record, reproduce, and distribute copies of minutes within seven days thereafter to all meeting participants.
3. During the months prior to the beginning of start-up or functional performance testing activities the Contractor will hold monthly commissioning progress meetings. The primary discussion will be the commissioning schedule. Thereafter, the construction schedule shall be revised to reflect any changes in the commissioning program.
4. Two weeks prior to the beginning of start-up or functional performance testing activities the Contractor will begin weekly commissioning progress meetings; which will continue thereafter until commissioning is complete.
5. The Owner's Representative may require additional meetings if the commissioning process appears to be behind schedule or if there are coordination problems. The Test Engineer may also request, in writing, additional meetings.

PART 2 - PRODUCTS

2.1 TEST EQUIPMENT

A. Provide industry standard test equipment required for performing the tests specified herein.

B. Instrumentation shall meet the following standards:

1. Be of sufficient quality and accuracy to test and measure system performance within the tolerances required to determine adequate performance.
2. Be calibrated on the manufacturer's recommended intervals with calibration tags permanently affixed to the instrument being used.
3. Be maintained in good repair and operating condition throughout the duration of use on this project.
4. Be recalibrated/repaired if dropped or damaged in any way since last calibrated.

C. Immersion Temperature Measuring Instruments, Liquids:

1. Range: -40°F to 120°F
   a. Type: Glass partial stem immersion
   b. Minimum accuracy: within 1/2 of scale division
   c. Resolution: One degree Fahrenheit (1°F)
2. Range: 0°F to 220°F
   a. Type: Glass partial stem immersion
   b. Minimum accuracy: within 1/2 of scale division
   c. Resolution: One degree Fahrenheit (1°F)

D. Air Temperature Measuring Instruments:

1. Range: -40°F to 120°F
   a. Type: Glass partial stem immersion
   b. Minimum accuracy: within 1/2 of scale division
   c. Resolution: One degree Fahrenheit (1°F)
2. Range: 0°F to 220°F
   a. Type: Glass partial stem immersion
   b. Minimum accuracy: within 1/2 of scale division
   c. Resolution: One degree Fahrenheit (1°F)

E. Hydronic Pressure Measuring Instruments:

1. Range: Indicated pressure shall be in the middle half of the instrument range.
   a. Type: Minimum "Grade A" gauge with stainless steel, alloy steel, monel or bronze Bourdon tube
   b. Minimum accuracy: Within ±0.25% of full scale
   c. Resolution: 0.5 PSI subdivisions on a 4.5" dial with a mirrored scale and knife-edge pointer.

F. Hydronic Differential Pressure Measuring Instruments:

1. Range: Indicated pressure shall be in the middle half of the instrument range.
   a. Type: Dual inlet, minimum "Grade A" gauge with dual stainless steel, alloy steel, monel or bronze Bourdon tubes and a single pointer
   b. Minimum accuracy: Within ±0.25% of full scale
   c. Resolution: 0.5 PSI subdivisions on a 4.5" dial with a mirrored scale and knife-edge pointer.

G. Air Pressure Measuring Instruments:

1. Range: Indicated pressure shall be in the inclined portion of the scale.
   a. Type: Inclined/vertical manometer

b. Resolution:
   1. Air velocity less than 1000 FPM; 0.005 inch graduations
   2. Air velocity between 1000 and 4000 FPM; 0.01 inch graduations
   3. Air velocity greater than 4000 FPM; 0.1 inch graduations

2.2 REPORTS

A. Testing, Adjusting and Balancing (TAB) Progress Reports: After TAB activities have begun, submit weekly TAB Progress Reports to the Owner's Representative. Identify

1. Systems or subsystems for which preliminary balancing is complete
2. Systems or subsystems for which final balancing is complete
3. Status of deficiencies and balancing problems encountered, including corrective actions taken
4. Updated schedule of remaining TAB activities

B. Installation Verification Audit: Prior to start-up, submit to the Owner's Representative for review and approval by the Architect and Commissioning Agent a report of installation verification audit activities. Identify equipment and components verified, deficiencies noted, corrective action taken and the dates and initials of the persons making the entries.

C. Start-up Deficiency Report: Within five days following start-up of each system or equipment, submit to the Owner's Representative Start-up Deficiency Report Forms. Identify systems and/or equipment started-up, deficiencies noted, corrective action taken and the dates and initials of the persons making the entries.

D. Functional Performance Test Deficiency Reports: At the end of each day in which functional performance tests are conducted, submit to the Owner's Representative Functional Performance Test Deficiency Report Forms for tests for which acceptable results were not achieved during the day.

1. Identify tests for which acceptable results were not obtained by test number and description, and equipment identification and location. Briefly describe observations about the performance which were associated with failure to achieve acceptable results. Identify the cause of failure if such is apparent,
2. When corrections have been completed, update the Functional Performance Test Deficiency Report Forms. Identify corrective action taken and the dates and initials of the persons making the entries.
3. Identify the schedule for retesting.

PART 3 - EXECUTION

3.1 BASIS OF DESIGN DOCUMENTATION

Edit and update basis of design narratives provided by the Owner's Representative. Incorporate the effect of approved substitution requests, change orders and responses to RFC's which change the information in the Architect's basis of design narratives. Basis of design includes design criteria and operations descriptions for systems itemized in Paragraph 3.2.

A. Design criteria shall include design conditions for each space as follows:

1. Indoor dry bulb temperature
2. Indoor relative humidity
3. Outdoor dry bulb temperature
4. Outdoor wet bulb temperature
5. Occupancy, hours, and degree of activity
6. Lighting and miscellaneous power
7. Ventilation -- recirculation and outside air
8. Internal loads
9. Special loads
10. Insulating R-values for roof, wall, glass, etc.
11. Percentage of glass -- fenestration
12. Type of glass, including coatings and solar coefficients
13. Building pressurization and infiltration
14. Building mass
15. Code requirements and impact on criteria
16. Air quality design criteria, i.e. ASHRAE 62-89
17. Noise criteria
18. Fire and life safety
19. Energy efficiency and cost
20. Maintainability

B. Operations description includes design intent, basic system type, major components, interrelation of components, capacity and sizing criteria, redundancy, diversity, automatic temperature control and sequence of operation, intended operation under all seasonal loads, changeover procedures, part-load strategies, occupied/unoccupied modes of operation, design setpoints of control systems with permissible adjustments, operation of system components in life-safety modes, energy conservation procedures, and any other engineered operational mode of the systems.

3.2 ONE-LINE DIAGRAMS

A. Provide one-line diagrams for the systems identified in 3.2.B.

B. One-line diagrams are intended to support narrative system descriptions and the overall commissioning process. Depending on the system in question, the following procedures for developing the one-line diagrams are to be employed.

1. Update AutoCAD-based one-line diagrams provided by the Architect for the following systems. Some revisions may be required to match the desired format for Commissioning Documents.

   a Electrical Power
   b Emergency Power
   c Hot Water Heating
   d Domestic Water
   e Steam and Condensate
   f Chilled Water Systems
   g Condenser Water Systems
   h Supply Air Systems
   i Return Air Systems
   j Exhaust Air Systems

2. Update and revise vendor supplied AutoCAD-based shop drawings; revise as required to match the format for Commissioning Documents. This method shall be employed for the following systems:

   a Lighting control
   b Security
   c Environmental Control System
   d Energy Management Control
   e Fire Suppression
   f Fire Alarm/Smoke Evacuation/Life Safety Graphics

3.3 COMMISSIONING PROCEDURE

A. Sequence of Testing: Commissioning shall proceed from lower to higher levels of complexity. For each discrete subsystem or system, testing at the lower level shall be completed prior to starting the next higher level of tests. In general, the order of testing, from lowest to highest is:

1. Static tests (e.g. duct leakage tests)

2. Component functional performance tests (i.e. motors, actuators and sensors) and start-up
3. Balancing
4. System functional performance tests
5. Intersystem functional performance tests

B. Retesting: Repeat at no additional cost to the Owner, the complete functional test procedure for each test for which acceptable results are not achieved. Repeat tests until acceptable results are achieved. Compensate the Owner for direct costs incurred as the result of tests repeated to achieve acceptable results. Fill out a new functional performance test data form for each retest.

C. Correction of Deficiencies:

1. Correct functional performance test deficiencies promptly and schedule retest.
2. Corrections during functional performance tests are generally prohibited to avoid consuming the time of personnel waiting for the test, but not involved in making the correction. Exceptions will be allowed if the cause of the failure is obvious and corrective action can be completed in less than five minutes. If corrections are made under this exception, the failure shall be noted on the functional performance test data form. A new functional performance test data form, marked "retest," shall be initiated after the correction has been made. The entire functional performance test procedure shall be repeated.

D. Owner Witness: Witnesses will be designated by the Owner to observe the commissioning process under the direction of the Commissioning Agent. Owner's witnesses shall provide no labor or materials in the commissioning process. The only function of the Owner's witnesses shall be to observe and comment on the progress and results of commissioning.

1. Provide access to permit the Owner's witness to directly observe the performance of the equipment being tested.
2. Provide ladders, scaffolding, and staging as required to permit the Owner's witness to directly observe the performance of the equipment being tested.
3. Notify the Owner's Representative of commissioning schedule changes at least 48 hours in advance if an Owner's witness will be involved.

3.4 OPERATIONS AND MAINTENANCE (O&M) MANUALS

A. Review O&M Manuals related to commissioning in accordance with the requirements indicated in Division 1.

B. Incorporate the standard technical literature into a systems-specific document; concise; to the point; and above all tailored specifically to this facility.

C. Obtain the equipment manufacturer's standard technical literature relevant to the operation and maintenance of the provided equipment. The literature shall be specifically oriented to the equipment provided, indicating all operation and maintenance procedures, parts lists, assembly/disassembly diagrams, and related information. Wiring diagrams must be complete and specific to the equipment provided.

D. Submit the draft document for review by the Owner's Representative, Architect, and Commissioning Agent to ensure completeness, proper written communications, and compliance with each reviewer's knowledge of the significant requirements.

3.5 INSTALLATION VERIFICATION

A. During construction, observe the work of the prime Contractor and subcontractors to assure that all installations are being made in accordance with the intent of the contract documents.

B. Before system start-up begins, conduct a final installation verification audit. The Contractor shall be responsible for completion of all work including change orders and punch list items to the satisfaction of the Owner's Representative. The audit shall include, but not be limited to, a check of:

1. Piping specialties including balance, control, and isolation valves.
2. Ductwork specialty items including turning devices; balance, fire, smoke and control dampers; and access doors.
3. Control sensor types and locations.
4. Identification of piping, valves, starters, gauges , thermometers, etc.
5. Documentation of prestart-up tests performed, including manufacturer's factory tests.
6. Accessibility to equipment in 1-3 above.

C. If any work is found to be incomplete, inaccessible, incorrect, or non-functional, make note of deficiencies and correct deficiencies before system start-up work proceeds.

3.6 SYSTEM START-UP

A. Develop a start-up plan. Commence with system start-up after approval has been given to the start-up plan and the prestart-up inspection has been completed by the Test Engineer. The Test Engineer shall witness system start-up and list all system and equipment deficiencies noted during start-up. The Contractor shall take corrective action on all system deficiencies noted and demonstrate to the Test Engineer suitable system operation. Notify Architect of start-up activities schedule at least five working days in advance. Owner's Representative and Commissioning Agent will physically witness start-up procedures. Test Engineer shall obtain signature of the Owner's Representative and Commissioning Agent indicating successful start-up.

3.7 START-UP DEFICIENCY LISTS

A. Prepare start-up deficiency list forms to report deficiencies discovered in conjunction with system start-up. Start-up deficiency forms shall indicate the system being started-up; the location and identification of the deficient equipment/material; date of observation; initials of the observer; observed deficiency; date of correction; initials of person making the correction; and corrective action taken.

B. Issue Start-up Deficiency Report Forms to the Contractor for corrective action, and to the Owner's Representative for follow-up. The Contractor shall advise the Test Engineer and Owner's Representative when all start-up deficiency list items have been corrected.

3.8 TESTING, ADJUSTING AND BALANCING (TAB)

A. Perform and coordinate air and hydronic balancing as required in 17595. Advise the TAB firm when systems are complete and ready for balancing. Start TAB as early as possible following systems start-ups and component functional performance tests, in order to be essentially complete prior to system functional performance tests. Coordinate TAB activities with other construction schedule activities.

B. Verify the accuracy of the TAB work prior to commencing any FPT activities which may be adversely affected by improper balancing.

3.9 FUNCTIONAL PERFORMANCE TEST PROCEDURES

A. Develop start-up procedures and functional performance test procedures and documentation to be used. Personnel experienced in the technical aspects of each system to be commissioned shall be engaged if necessary to augment the expertise of the Test Engineer. Include functional performance test procedures and functional performance test data sheets for each system based upon actual system configuration. Emphasis shall be placed on testing procedures which will conclusively determine actual system performance and compliance with the design.

B. Test procedures shall fully describe system configuration and steps required for each test; appropriately documented so that another party can repeat the tests with virtually identical results.

C. Acceptance test procedures must confirm the performance of systems to the extent of the design intent and applicable code under which the project was permitted. When a system is accepted, the Commissioning Agent must be assured that the system is complete, works as intended, is correctly documented, and that the Owner's staff are trained in the operation and maintenance of the system.

D. The majority of mechanical equipment requires integral safety devices to stop/prevent equipment operation unless minimum safety standards or conditions are met. This could include adequate oil pressure, proof-of-flow, non-freezing conditions, maximum head pressure, etc. Functional performance test procedures shall demonstrate the actual performance of safety shutoffs in a real or closely-simulated conditions of failure.

E. Systems may include safety devices and components that control a variety of equipment operating as a system. Interlocks may be hard-wired or installed via software. Functional performance test procedures shall demonstrate these interlocks.

F. Inform appropriate subcontractor(s) and vendor(s) before commissioning is started as to what the test and expected results will be. Whereas some test results and interpretations may not become evident until the actual tests are performed, all participants should have a reasonable understanding of the requirements . The commissioning plan must address the requirements and be distributed to all participants involved with that particular system.

3.10 REVIEW SOFTWARE DOCUMENTATION

A. Review vendor/contractor provided detailed BAS software documentation. This includes obtaining BAS program documentation, a review of the programming approach, interface with other systems (e.g. lighting, fire alarm, security, clock, emergency generator monitoring, sump pumps, and utility metering), and a review of the specific software routines as applied to this project. Discrepancies in programming approaches will be resolved to provide the Owner with the most appropriate, simple and straight-forward approach to software routines.

B. Provide copies of all of the preceding material, including electronic copes of all control system software, to the Owner's Representative so that Owner's technical staff can simulate system operation and troubleshoot the software.

3.11 TRAINING

A. Prepare and submit for approval a training plan. Training plan shall include for each training session

1. Dates, start and finish times, and locations,
2. Outline of the information to be presented,
3. Names and qualifications of presenters,
4. List of texts and other materials required to support training

B. Obtain assistance from appropriate subcontractors and vendors to provide training for the Owner's operations staff as specified in Divisions 15, 16 and 17.

C. Provide videotape documentation of training of the Owner's staff for each system. Training will be in a classroom setting with the appropriate schematics, handouts and audio/visual training aids.

D. Catalog training video tapes and deliver to the Owner with the O&M manuals in accordance with Divisions 15, 16 and 17.

E. Host each training session.

1. Provide program overview and curriculum guidance.
2. Obtain signatures of attendees on a sign-in list.

F. Equipment vendors provide training on the specifics of each system and philosophy, troubleshooting, and repair techniques as specified in the relevant sections of this specification.

G. Installation subcontractors provide training on peculiarities specific to this project and job specific experience as specified in the relevant sections of this specification.

3.12 RECORD DRAWINGS

Review record documents to verify accuracy

3.13 FUNCTIONAL COMPLETION

The Commissioning Agent will review Contractor's records of completion of Division 17 requirements. Upon receiving evidence of satisfactory completion of Functional Completion requirements in Section 01700, the Test Engineer will submit to the Owner a recommendation to accept Functional Completion.

3.14 EXCLUSIONS

A. The Owner's Representative and Commissioning Agent are not responsible for construction means, methods, job safety, or any management function related to commissioning on the job site.

B. The Contractor shall provide all technician services requiring tools or the use of tools to test, adjust or otherwise bring equipment into a full operational state.

END OF SECTION

Appendix 4-6

SECTION 17500 - COMMISSIONING, HVAC SYSTEMS

GUIDE SPECIFICATION

The following guide specification is intended to be modified and included in the construction contract documents. Items to be modified will be decided by consultation involving the owner's project manager and the A/E. The A/E is expected to modify this and other specifications as necessary to accurately reflect commissioning requirements based upon specific systems, conditions, and requirements of the project.

PART 1 - GENERAL

1.1 DESCRIPTION

A. The purpose of this section is to describe the general commissioning process specific to the HVAC systems and equipment. HVAC systems include hot water heating, chilled water, steam/condensate, supply air and exhaust air systems.

1.2 RELATED WORK

A. Reference Sections 01650, 17100 and 17110 for primary commissioning requirements and responsibilities.

B. Reference Section 15995 specifications for specific mechanical contractor related work and Divisions 15 and 16 for overall subcontractor requirements. Section 17500 is the overall requirement for HVAC commissioning, whereas other sections relate to specific procedures relative to supply air, exhaust air, hot water heating, central cooling water, steam and condensate, and environmental control systems, etc. Refer to Sections 17510, 17520, 17530, 17540, 17550, and 17590 for system specifics.

C. Refer to Section 17595 for testing, adjusting and balancing (TAB) requirements. TAB shall be substantially complete before performing FPTs required in this section.

PART 2 - PRODUCTS

2.1 TEST EQUIPMENT

A. Refer to Section 17595 for tools and equipment required. The Contractor shall provide all necessary test equipment.

PART 3 - EXECUTION

3.1 CONSTRUCTION OBSERVATION

A. Obtain and review design documents for overall design intent and the overall required systems configurations.

B. Obtain and review shop drawings and submittals for installation criteria and the required construction details, as they support and further define the systems features.

C. Make general inspections at the job site and review the following configuration, quality of construction, adherence to design requirements, and conformance with shop drawings and submittal information.

D. The Test Engineer shall provide periodic observations of the HVAC systems equipment, ductwork, and piping systems as constructed. Observations shall commence with arrival of major components on the job site, and continue through the construction phase and into the start-up phases of work. In addition to general observation services, the Test Engineer will make note of, or obtain, the following specific system features:

E. Prime Movers/Major Equipment:

1. Fans, Pumps, and Chillers:

   a. Condition of equipment as delivered/installed
   b. Equipment data/compliance with specifications and shop drawings
   c. Performance curves
   d. Installation per design documents

F. Accessories

1. Supply, Return, and Exhaust Air Systems:

   a. Balancing dampers/fit and integrity
   b. Fire dampers/fit and integrity
   c. Control dampers/fit and integrity
   d. Smoke dampers/fit and integrity
   e. Isolation dampers/fit and integrity

2. Chilled, Central Cooling, Hot, Heat Pump and Condenser Water Systems:

   a. Balance cocks/location and accessibility

b. Flow stations/location and accessibility
c. Strainers/location and accessibility and strainer mesh
d. Isolation valves/location and accessibility
e. Control valves/location and accessibility

3. Steam/Condensate Systems:

a. Traps/location and accessibility
b. Drip legs and accessibility
c. Condensate return stations and accessibility

G. Distribution Systems:

1. Duct:

a. Size and configuration
b. Fittings/transitions and takeoffs
c. Seams and joints/integrity and sealing
d. Hangers and bracing. Connections
f. Sealing/sealers and joints
g. Thickness per specifications/SMACNA standards

2. Pipe:

a. Size and configuration
b. Fittings
c. Connections
d. Hangers and bracing
e. Materials per specifications

H. Terminal Units:

1. Air Terminal/Boxes:

a. Number, size configuration per plans and specifications
b. Balance dampers (if applicable)
c. Controls components and configurations
d. Entrance and exit conditions per requirements

2. Coils:

a. Supply and return piping connections

   - b. Ductwork transitions
   - c. Sealing of ducts penetrations
   - d. Fin integrity and straightness

I. Controls:

1. Components and configurations per shop drawings

2. Organization and layout of control panels

3. Sensors in proper locations

4. Wiring and pneumatic piping per specifications

5. Labeling and identification/all components, wiring, and piping

3.2 CLEANING

A. See individual subsections. Witness and verify that all systems and equipment have been cleaned per the requirements of the contract documents.

3.3 EQUIPMENT SAFETY DEVICE CHECKS

A. See individual system commissioning procedures. Submit for approval safety device check procedures in accord with manufacturer's recommended start-up instructions.

3.4 ACCEPTANCE CRITERIA

A. The primary purpose of this section is to witness and verify all of the sequence of operations of the systems shown on the M9 drawings and additionally called for in the specification section 15900 of the contract documents.

B. Each function and test shall be performed under conditions which simulate as close to an actual condition as possible. To that end, the Contractor shall provide al necessary materials and temporary system modifications to provide flows, pressures, temperatures, etc necessary to false load the system being tested in order to prove and verify proper operation. Reliance on simulated signals from the DDC system or other indirect indicators is not acceptable. At satisfactory completion of all verified tests, the building system being tested shall be returned to the condition required by the contract documents as a complete and operational systems.

C. Demonstrate to the Owner's Representative successful execution of the following FPTs (functional performance tests) in accordance with approved FPT procedures as described in Test Procedures in this Section.

D. See Section 17510 for testing of the Supply Air Systems, 17520 for testing of Exhaust Air Systems and 17560 for the Heat Pump System. It is the intent of this section to test any air based systems and functions which have not been tested in the three other sections. See Sections 17510, 17520 and 17560 for requirements.

E. Auditoria - Variable Air Volume Boxes

1. Variable Air volume Units - Occupied Cooling Mode

   a. System/Equipment to be Tested: Variable air volume boxes 2-1.2, 2-1.3, 2-1.4, their associated piping, distribution, and controls in Auditorium 105; Variable air volume boxes 2-1.5, 2-1.6, 2-1.7, their associated piping, distribution, and controls in Auditorium 125.
   b. Functions to be Tested: Operation and staging of boxes and return control damper in each auditorium during an occupied cooling mode.
   c. Conditions of the Test: Provide cooling load for testing at 100%, 75%, 50% and 25% load conditions. Monitor and record primary air flow at each box, primary air temperature and damper position, control valve position, entering and leaving water temperatures, leaving air temperature, return damper position, return air volume and room temperature.
   d. Acceptable Results: The boxes and control damper operate per the control sequence and the room is cooled to, and maintains, space setpoint within ±2°F. Each test shall be conducted for 30 minutes. Each auditorium shall be tested.

2. Variable Air Volume Units - Occupied Heating Mode

   a. System/Equipment to be Tested: Variable air volume boxes 2-1.2, 2-1.3, 2-1.4, their associated piping, distribution, and controls in Auditorium 105; Variable air volume boxes 2-1.5, 2-1.6, 2-1.7, their associated piping, distribution, and controls in Auditorium 125.
   b. Functions to be Tested: Modulation of the each heating coil control valve, operation of the box primary air flow and damper position, and staging of the individual boxes and tracking of the return control damper.
   c. Conditions of the Test: Cool space to 60°F, turn off cooling source. Monitor and record primary air flow at each box, primary air temperature, control valve position, entering and leaving water temperatures, leaving air temperature, return damper position, return air volume and room temperature.

d. Acceptable Results: The boxes and damper operate per the control sequence and the room is heated to and maintains space setpoint ±1°F for 30 minutes. Verify transition from heating to cooling that there is no simultaneous heating and cooling. Each auditorium shall be tested.

3. Variable Air Volume Units - Unoccupied Cooling Mode

   a. System/Equipment to be Tested: Variable air volume boxes 2-1.2, 2-1.3, 2-1.4, their associated piping, distribution, and controls in Auditorium 105; Variable air volume boxes 2-1.5, 2-1.6, 2-1.7, their associated piping, distribution, and controls in Auditorium 125.
   b. Functions to be Tested: Operation and staging of boxes and return control damper in each auditorium during an unoccupied cooling mode.
   c. Conditions of the Test: Heat space to 95°F, turn off heat source. Monitor and record primary air flow at each box, primary air temperature, control valve position, entering and leaving water temperatures, leaving air temperature, return damper position, return air volume and room temperature.
   d. Acceptable Results: Each box operates per the control sequence and the room is cooled to, and maintains, space setpoint for 30 minutes. Verify transition from cooling to heating that there is no simultaneous heating and cooling. Each auditorium shall be tested.

4. Variable Air Volume Units - Unoccupied Heating Mode

   a. System/Equipment to be Tested: Variable air volume boxes 2-1.2, 2-1.3, 2-1.4, their associated piping, distribution, and controls in Auditorium 105; Variable air volume boxes 2-1.5, 2-1.6, 2-1.7, their associated piping, distribution, and controls in Auditorium 125.
   b. Functions to be Tested: Operation and staging of boxes and return control damper, modulation of the heating coil control valves and primary air flow to each box in each auditorium during an unoccupied heating mode.
   c. Conditions of the Test: Cool space to 50°F, turn off cooling source. Monitor and record operation of primary air flow at each box, primary air temperature, control valve position, entering and leaving water temperatures, leaving air temperature, return damper position, return air volume and room temperature.
   d. Acceptable Results: Each box operates per the control sequence and the room is heated to and maintains space setpoint for 30 minutes. Verify transition from heating to cooling that there is no simultaneous heating and cooling. Each auditorium shall be tested.

5. Variable Air Volume Units - Control Power Failure

    a. System/Equipment to be Tested: Variable air volume boxes 2-1.2, 2-1.3, 2-1.4, their associated piping, distribution, and controls in Auditorium 105; Variable air volume boxes 2-1.5, 2-1.6, 2-1.7, their associated piping, distribution, and controls in Auditorium 125.
    b. Functions to be Tested: Fail safe position of control dampers and valves when control power is lost at panel.
    c. Conditions of the Test: Begin the test with all systems operating; disengage control power at panel.
    d. Acceptable Results: Dampers and valves fail to their "safe" positions per the specifications. Each auditorium shall be tested.

F. Generic Office with VAV/FVAV and CU

1. Generic Office with VAV/FVAV and CU - Simultaneous Heating and Cooling

    a. System/Equipment to be Tested: Variable air volume boxes (VAVs), fan powered variable air volume boxes (FVAVs), perimeter convection units (CUs) their associated piping, distribution, and controls. A random selection of 10% of the spaces shall be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed. These tests may be performed in conjunction with sections 17510 and section 17530.
    b. Functions to be Tested: No simultaneous heating and cooling.
    c. Conditions of the Test: The space shall be "cooled" to 50°F. Monitor and record operation of primary air flow at each box, primary air temperature, control valve position, entering and leaving water temperatures, leaving air temperature; convection unit valve position entering and leaving water temperatures, and room temperature. "Heat" the space to 85°F and test cooling cycle.
    d. Acceptable Results: The space operates per the control sequence without simultaneous heating and cooling. Monitor and record each mode for 20 minutes.

2. Generic Office with VAV/FVAV and CU - Occupancy Sensor

    a. System/Equipment to be Tested: Variable air volume boxes (VAVs), fan powered variable air volume boxes (FVAVs), perimeter convection units (CUs) their associated piping, distribution, and controls. A random selection of 10% of the spaces shall be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed. These tests may be performed in conjunction with sections 17510 and section 17530.

b. Functions to be Tested: Verify operation of operation of occupancy sensor and switch between occupied and unoccupied modes when triggered by local occupancy sensor.

c. Conditions of the Test: Begin test with space unoccupied. Confirm control status. Enter room and verify control system confirmation of occupancy within one minute. Exit room. Confirm control system change to "unoccupied within one minute. Monitor and record activation VAV box operation, valve positions and space temperature for test.

d. Acceptable Results: Control system switches to "occupied" and back to unoccupied mode. Provide computer printout of status and room setpoints.

G. Generic Office with Heat Pump and CU

1. Generic Office with heat pump (HP) and CU - Simultaneous Heating and Cooling

a. System/Equipment to be Tested: Heat pumps, perimeter convection units (CUs) their associated piping, distribution, and controls. A random selection of 10% of the spaces shall be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed. These tests may be performed in conjunction with sections 17530 and section 17560.

b. Functions to be Tested: No simultaneous heating and cooling.

c. Conditions of the Test: The space shall be "cooled" to 50°F. Monitor and record operation of heat pump compressor, leaving air temperature, convection unit valve position, entering and leaving water temperatures, and room temperature. "Heat" the space to 85°F and test cooling cycle.

d. Acceptable Results: The space operates per the control sequence without simultaneous heating and cooling. Monitor and record each mode for 20 minutes.

2. Generic Office with Heat Pump and CU - Occupancy Sensor

a. System/Equipment to be Tested: Heat pumps, perimeter convection units (CUs) their associated piping, distribution, and controls. A random selection of 10% of the spaces shall be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed. These tests may be performed in conjunction with sections 17530 and section 17560.

b. Functions to be Tested: Verify operation of operation of occupancy sensor and switch between occupied and unoccupied modes when triggered by local occupancy sensor.
c. Conditions of the Test: Begin test with space unoccupied. Confirm control status. Enter room and verify control system confirmation of occupancy within one minute. Exit room. Confirm control system change to "unoccupied within one minute. Monitor and record activation VAV box operation, valve positions and space temperature for test.
d. Acceptable Results: Control system switches to "occupied" and back to unoccupied mode. Provide computer printout of status and room setpoints.

H. Generic Laboratory with FVAV and FCU

1. Generic Laboratory with FVAV and FCU - Simultaneous Heating and Cooling

a. System/Equipment to be Tested: Fan powered variable air volume boxes (FVAVs), fan coil units (FCUs), their associated piping, distribution, and controls. HVAC A random selection of 10% of the spaces shall be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed. These tests may be performed in conjunction with section 17510.
b. Functions to be Tested: No simultaneous heating and cooling.
c. Conditions of the Test: The space shall be "cooled" to 50°F. Monitor and record operation of primary air flow at each box, primary air temperature, control valve position, entering and leaving water temperatures, leaving air temperature; fan coil fan operation, cooling coil valve position, entering and leaving water temperatures, and room temperature. "Heat" the space to 85°F and test cooling cycle.
d. Acceptable Results: The space operates per the control sequence without simultaneous heating and cooling. Monitor and record each mode for 20 minutes.

2. Generic Laboratory with FVAV and FCU - Occupancy Sensor

a. System/Equipment to be Tested: Fan powered variable air volume boxes (FVAVs), fan coil units (FCUs), their associated piping, distribution, and controls. HVAC A random selection of 10% of the spaces shall be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed. These tests may be performed in conjunction with section 17510.

b. Functions to be Tested: Verify operation of operation of occupancy sensor and switch between occupied and unoccupied modes when triggered by local occupancy sensor.
c. Conditions of the Test: Begin test with space unoccupied. Confirm control status. Enter room and verify control system confirmation of occupancy within one minute. Exit room. Confirm control system change to "unoccupied within one minute. Monitor and record activation VAV box operation, valve positions and space temperature for test.
d. Acceptable Results: Control system switches to "occupied" and back to unoccupied mode. Provide computer printout of status and room setpoints.

I. Chemical Use Laboratory with VAV and FCU

1. Chemical Use Laboratory with VAV and FCU - Simultaneous Heating and Cooling

a. System/Equipment to be Tested: Variable air volume boxes (VAVs), fan coil units, their associated piping, distribution, and controls. A random selection of 10% of the spaces shall be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed. These tests may be performed in conjunction with section 17510.
b. Functions to be Tested: No simultaneous heating and cooling.
c. Conditions of the Test: The space shall be "cooled" to 50°F. Monitor and record operation of primary air flow at each box, primary air temperature, control valve position, entering and leaving water temperatures, leaving air temperature; fan coil fan operation, cooling coil valve position, entering and leaving water temperatures, and room temperature. "Heat" the space to 85°F and test cooling cycle.
d. Acceptable Results: the space operates per the control sequence without simultaneous heating and cooling. Monitor and record each mode for 20 minutes.

J. Shop, Room 076

1. Shop, Room 076 - Differential Pressure Alarm

a. System/Equipment to be Tested: VAV boxes, exhaust VAV boxes, snorkel exhausts, paint booth, air distribution and control systems serving room 076.
b. Functions to be Tested: Activation of an Alarm condition in the event the room becomes positively pressurized (test 1) or excessively negative relative to the adjacent corridor (test 2).

c. Conditions of the Test: Disengage the paint booth exhaust fan, and the snorkel exhaust system during test one; disengage one supply VAV terminal during the second test.
d. Acceptable Results: Confirmation of the local and control "Alarm" condition.

K. Clean Rooms

1. Clean Room B023B - Pressure Differential Pressure Alarm

   a. System/Equipment to be Tested: All systems serving rooms B023B, including AHU-12, VAV boxes, fume hoods, air distribution and control systems.
   b. Functions to be Tested: Activation of an Alarm condition in the event the room becomes negatively pressurized or excessively positive relative to room B023.
   c. Conditions of the Test: Disengage one supply VAV box during test one; restrict air flow to one fume hood by obstructing the hood by pass with the sash down during the second test.
   d. Acceptable Results: Confirmation of the local and control "Alarm" condition.

2. Clean Room B023 - Pressure Differential Pressure Alarm

   a. System/Equipment to be Tested: All systems serving rooms B023, including AHU-11, VAV boxes, fume hoods, air distribution and control systems.
   b. Functions to be Tested: Activation of an Alarm condition in the event the room becomes negatively pressurized or excessively positive relative to the room B025.
   c. Conditions of the Test: Disengage one supply VAV box during test one; restrict air flow to one fume hood by obstructing the hood by pass with the sash down during the second test.
   d. Acceptable Results: Confirmation of the local and control "Alarm" condition.

3.5 TEST PROCEDURES

A. Submit for approval detailed FPT procedures corresponding to the FPT criteria in Acceptance Criteria in this Section. FPT procedures shall be detailed test instructions, written with sufficient step-by-step information to allow a test to be repeated under identical conditions. List the value for all setpoints and inputs, positions of adjustable devices and acceptable results for each condition tested. Provide a unique alpha-numeric identification for each FPT procedure.

B. Submit for approval test procedure check-off sheets. Number each test procedure check-off item with the same number as the corresponding FPT procedure.

C. Demonstrate successful execution of FPT's listed under Acceptance Criteria in this Section. Sign-off each successful test and obtain the sign-off of the Commissioning Agent or other Owner-designated witness.

END OF SECTION

Appendix 4-7

SECTION 17510 - COMMISSIONING, SUPPLY AIR SYSTEMS

GUIDE SPECIFICATION

The following guide specification is intended to be modified and included in the construction contract documents. Items to be modified will be decided by consultation involving the owner's project manager and the A/E. The A/E is expected to modify this and other specifications as necessary to accurately reflect commissioning requirements based upon specific systems, conditions, and requirements of the project.

PART 1 - GENERAL

1.1 DESCRIPTION

A. The purpose of this section is to describe the commissioning process specific to the supply air systems and equipment.

1.2 RELATED WORK

A. Reference Sections 01650, 17100 and 17110 for primary commissioning requirements and responsibilities.

B. Reference Section 15995 for contractor requirements in support of the commissioning process. Refer to Division 15 specifications and plans and contractor shop drawings for system configuration and details of required construction.

C. Reference Section 17595 for testing, adjusting and balancing (TAB) requirements. TAB shall be substantially complete before performing FPTs required in this section.

PART 2 - PRODUCTS

2.1 TEST EQUIPMENT

A. Refer to Section 17595 for tools and equipment required. The Contractor shall provide all necessary test equipment.

PART 3 - EXECUTION

3.1 CONSTRUCTION OBSERVATION

A. Obtain and review design documents for overall design intent and the overall required systems configurations.

B. Obtain and review shop drawings and submittals for installation criteria and the required construction details, as they support and further define the systems features.

C. Make general inspections at the job site and shall review the following for configuration, quality of construction, adherence to design requirements, and conformance with shop drawings and submittal information.

D. The Test Engineer shall provide periodic observations of the HVAC systems equipment, ductwork, and piping systems as constructed. Observations shall commence with arrival of major components on the job site, and continue through the construction phases and into the start-up phases of work. In addition to general observation services, the Test Engineer will specifically observe the following specific system features:

1. Prime Movers/Major Equipment:

   a. Fans:

      1. Conditions of equipment as delivered/installed/damage/cleanliness
      2. Equipment data/compliance with specifications and shop drawings
      3. Performance curves/configuration per submitted documents
      4. Installation per design documents/plans and specifications
      5. Equipment mounting and anchoring devices
      6. Vibration isolation devices

   b. Accessories/Supply Air Systems:

      1. Balancing dampers/fit and integrity/locking quadrants
      2. Fire dampers/fit and integrity/fusible links
      3. Control dampers/fit and integrity/seals/linkage/motor mounting
      4. Smoke dampers/fit and integrity/linkage motor mounting
      5. Isolation dampers/fit and integrity/seals/linkage/motor mounting.

   c. Distribution Systems/Ductwork:

      1. Size and configuration
      2. Fittings/transitions and takeoffs
      3. Seams and joints/integrity and sealing
      4. Hangers and bracing
      5. Flexible connections
      6. Sealing/sealers and joints

        7. Thickness per specifications/SMACNA standards
        8. Lining (if applicable) per SMACNA standards

    d. Terminal Units:

        1. Air Terminal/Boxes:

            a. Number, size configuration per plans and specifications
            b. Balance dampers (if applicable)
            c. Controls components and configurations
            d. Entrance and exit conditions per requirements
            e. Sound attenuation per plans and specifications
            f. Entrance conditions to box/length of straight runs

        2. Coils:

            a. Components and configurations per shop drawings
            b. Organization and layout of control panels
            c. Sensors in proper locations
            d. Wiring and pneumatic piping per specifications
            e. Labeling and identification/all components, wiring, and piping.

3.2 CLEANING

A. Test Engineer and Commissioning Agent shall witness and verify. See Division 15 requirements.

3.3 TESTS

A. Test Engineer and Commissioning Agent shall witness and verify tests performed under Section 15810.

3.4 EQUIPMENT SAFETY DEVICE CHECKS

A. Submit for approval safety device check procedures in accord with manufacturers' recommended start-up instructions.

3.5 ACCEPTANCE CRITERIA

A. The primary purpose of this section is to witness and verify all of the sequence of operations of the supply air systems shown on the M9 drawings and additionally called for in the specification section 15900 of the contract documents; and equipment capacities submitted. Provide trend logs for each test, recording data every 2 minutes.

B. Each function and test shall be performed under conditions which simulate as close to an actual condition as possible. To that end, the Contractor shall provide al necessary materials and temporary system modifications to provide flows, pressures, temperatures, etc necessary to false load the system being tested in order to prove and verify proper operation. Reliance on simulated signals from the DDC system or other indirect indicators is not acceptable. At satisfactory completion of all verified tests, the building system being tested shall be returned to the condition required by the contract documents as a complete and operational systems.

C. Demonstrate to the Owner's Representative successful execution of the following FPTs (functional performance tests) in accordance with approved FPT procedures as described in Test Procedures in this Section.

D. Air Handling Units

1. Air Handling Units - Mixed Air Control

   a. System/Equipment to be Tested: AHU-1 through AHU-9, control system.
   b. Functions to be Tested: damper and control valve actuation in order to maintain temperature setpoint and minimum outside air.
   c. Conditions of the Test: test damper modulation capability when outside air temperature is below 45°F, around 60°F and above 82°F. Test system under 25%, 50%, 75% and 100% air flow within the design tolerances.
   d. Acceptable Results: every mode of the system operation and every item in the control description shall be proved Retest operation with carbon dioxide concentrations above 800 ppm in the return air stream.

2. Air Handling Units - Cooling and Heating Coil Capacity

   a. System/Equipment to be Tested: AHU-1 through AHU-9, and their associated control systems.
   b. Functions to be Tested: capacity of the heating and cooling coils.
   c. Conditions of the Test: conditions at heating coil shall be as scheduled on drawings, measure and record leaving heating coil and cooling coil temperature, water flows, valve positions and air flow for a period of 20 minutes; repeat test while increasing coil entering conditions by 15°F intervals up to the scheduled cooling coil entering coil air temperature. Test coils at design conditions and 100% air flow; retest at 25%, 50%, and 75% air flow.

d. Acceptable Results: coils provide the scheduled/submitted capacities, and supply air temperature is maintained throughout the test; when the heating coil is operating the cooling coil has modulated closed; and while the cooling coil is operating, the heating coil has modulated closed. Verify tight shutoff of heating and cooling coil valves.

3. Air Handling Units - Freeze Protection

   a. System/Equipment to be Tested: AHU-1 through AHU-9, associated control dampers and control system.
   b. Functions to be Tested: freeze protection alarm, valve and damper responses.
   c. Conditions of the Test: provide means to falsely "chill" freeze protection thermostat: do NOT subject coils to a true freeze condition.
   d. Acceptable Results: the freeze protection sequence scheduled on the drawings is confirmed.

4. Air Handling Units - Supply Fan/Return Fan/Exhaust Fan Interlock

   a. System/Equipment to be Tested: AHU-1 through AHU-9, and associated control system and associated return and exhaust systems. Tests may be performed in conjunction with 17810.
   b. Functions to be Tested: confirm interlock function between supply fans and their associated return or return and exhaust fans.
   c. Conditions of the Test: begin the test with all the associated fans of the system (as described on the control diagrams) "ON". Shut off each of the fans is individually at the disconnect while the remaining are "ON".
   d. Acceptable Results: the unit confirms the interlock function.

5. Air Handling Units - Supply Fan Starting and Stopping

   a. System/Equipment to be Tested: AHU-1 through AHU-9, associated control and fire alarm systems.
   b. Functions to be Tested: stopping of supply air fans as per control drawings.
      1. Freeze protection thermostat shutdown (see paragraph 3)
      2. General fire alarm (in conjunction coordinate with 17800)
      3. Starter or Disconnect Manual Shutdown (Coordinate with paragraph 4)
      4. DDC Operator Command
   c. Conditions of the Test: begin the test with all the associated fans of the system (as described on the control diagrams) "ON". Each test shall be performed individually.
   d. Acceptable Results: the control system is confirmed.

6. Air Handling Units - Supply Duct Static Pressure Control

   a. System/Equipment to be Tested: AHU-1 through AHU-9, their associated air distribution and control systems and variable speed drives.
   b. Functions to be Tested: modulation of the fan speeds in correlation to static pressure sensing.
   c. Conditions of the Test: begin the test with all the associated variable air volume boxes on the system calling for maximum air flow, measure and record drive speed, air flow, and static pressure for 20 minutes. Reduce air flow to 75% over 5 minutes. Repeat test at 75%, 50% and 25% air flow.
   d. Acceptable Results: The static pressure is maintained, ±0.10" wg at the sensor (by varying the fan speed) as the air flow demand is reduced.

7. Air Handling Units - Return Fan Tracking Control

   a. System/Equipment to be Tested: AHU-1 through AHU-9, their associated air distribution and control systems and variable speed drives.
   b. Functions to be Tested: modulation of the return fan speeds in correlation to supply fan speeds and air flow offsets.
   c. Conditions of the Test: begin the test with all the associated variable air volume boxes on the system calling for maximum air flow, measure and record static pressure, supply and return air flows, and drive speed for 20 minutes. Reduce supply air flow to 75% over 5 minutes. Repeat test at 75%, 50% and 25% air flow.
   d. Acceptable Results: The return fan maintains the air flow offset within 5%.

8. Air Handling Units - Branch Air Flow

   a. System/Equipment to be Tested: AHU-1 through AHU-9, EF-2, EF-4 and EF-6, their associated air distribution and control systems. Each branch containing a control damper shall be tested.
   b. Functions to be Tested: modulation of the branch control dampers in correlation to measured supply air flows and air flow offsets.
   c. Conditions of the Test: begin the test with all the associated variable air volume boxes on the floor calling for maximum air flow, measure and record supply and return flows for 20 minutes. Reduce branch supply air flow to 75% over 5 minutes. Repeat test at 75%, 50% and 25% air flow. However, do not reduce supply air to any boxes beyond their night setback air flow.
   d. Acceptable Results: The return dampers maintain the air flow offset at each branch as the supply air is reduced. Air flow measurements shall be confirmed by pitot traverse of the branches being tested and/or by performing an inventory of the individual VAV terminal units.

9. Air Handling Units - Exhaust Duct Static Pressure Control

   a. System/Equipment to be Tested: AHU-2, AHU-4, AHU-6, EF-2, EF-4 and EF-6, their associated air distribution and control systems.
   b. Functions to be Tested: modulation of the exhaust fan speeds in order to maintain exhaust static pressure.
   c. Conditions of the Test: begin the test with all the associated exhaust variable air volume boxes on the system calling for maximum air flow, measure and record static pressure for 20 minutes. Test again at 75%, 50%, and minimum supply air flow.
   d. Acceptable Results: The static pressure is maintained at the sensor ±0.10"wg.

10. Air Handling Units - Loss of Control Power

    a. System/Equipment to be Tested: AHU-1 through AHU-9, EF-2, EF-4 and EF-6, their associated air distribution and control systems.
    b. Functions to be Tested: fail safe position of control dampers and valves when control power is lost; and return to normal operation once power is restored.
    c. Conditions of the Test: begin the test with all systems operating; disengage control power.
    d. Acceptable Results: valves and dampers fail to their "safe" positions and return to normal operation upon restoration of power.

11. Air Handling Units - Loss of Power

    a. System/Equipment to be Tested: AHU-1 through AHU-9, EF-2 EF-4 and EF-6, their associated air distribution and control systems. Test may be performed in conjunction with other Sections in Division 17.
    b. Functions to be Tested: shutdown of the units in an emergency power mode and their return to normal operation once power is restored.
    c. Conditions of the Test: begin the test with all systems operating; disengage normal power, switch to emergency power and then restore normal power.
    d. Acceptable Results: Unit cycles off and outside air dampers close; and the system returns to power per the specified sequence.

E. Air Handling Units - Heat Wheel

   1. Air Handling Units - Supply Air Temperature Control

      a. System/Equipment to be Tested: AHU-10 and its distribution system.

b. Functions to be Tested: modulation of heat wheel speed in order to maintain supply air discharge temperature control.
c. Conditions of the Test: test when outside air is 30°F or below, and return air at 74°F, the wheel adjusts speed to provide 55°F. Monitor and record outside air, supply air, return air and exhaust air temperatures, and wheel speed for 20 minutes. Provide false condition at temperature sensor in increments of 15°F, monitor and record wheel speed for each 20 minute test. Provide at 24°F input and verify wheel speed with submitted.
d. Acceptable Results: the supply air temperature is maintained and the wheel speed is adjusted per the control sequence.

2. Air Handling Units - Freeze Protection

a. System/Equipment to be Tested: AHU-10 associated control system.
b. Functions to be Tested: freeze protection alarm and air handling unit response.
c. Conditions of the Test: provide means to falsely "chill" freeze protection thermostat.
d. Acceptable Results: the freeze protection sequence scheduled on the drawings is confirmed.

3. Air Handling Units - Supply and Exhaust Fan Starting and Stopping

a. System/Equipment to be Tested: AHU-10 associated control and fire alarm systems.
b. Functions to be Tested: stopping of supply air fans as per control drawings.
    1. Freeze protection thermostat shutdown (see paragraph 2)
    2. General fire alarm (Coordinate with 17800)
    3. Starter or Disconnect Manual Shutdown
    4. DDC Operator Command
c. Conditions of the Test: begin the test with all the associated fans of the system (as described on the control diagrams) "ON". Each test shall be performed individually.
d. Acceptable Results. the control system is confirmed.

4. Air Handling Units - Loss of Control Power

a. System/Equipment to be Tested: AHU-10, its associated air distribution and control systems.
b. Functions to be Tested: fail safe position of control dampers when control power is lost; and return to normal operation once power is restored.
c. Conditions of the Test: begin the test with all systems operating; disengage control power.

d. Acceptable Results: dampers fail to their "safe" positions.

5. Air Handling Units - Loss of Power

a. System/Equipment to be Tested: AHU-10 and its associated air distribution and control systems. This test may be performed in conjunction with other tests performed under Division 17.
b. Functions to be Tested: shutdown of the unit in an emergency power mode and its return to normal operation once power is restored.
c. Conditions of the Test: begin the test with all systems operating; disengage power, switch to emergency power and then restore to normal.
d. Acceptable Results: Unit cycles off and is returned to power per the specified sequence.

F. Air Handling Units - Clean Rooms

1. Air Handling Units - Mixed Air Monitoring

a. System/Equipment to be Tested: AHU-11, AHU-12, EF-33 and their associated air distribution, piping and control systems.
b. Functions to be Tested: air flow maintenance.
c. Conditions of the Test: all makeup air being provided, and exhaust flows being maintained at low speed and high speed.
d. Acceptable Results: makeup air flow tracks the operation of EF-33 when reduced to low speed, record and monitor for 20 minutes. Return exhaust fan EF-33 to high speed. Record and monitor exhaust and makeup air flows (cfms) and pressure differential at entry door to each area served by the air handing unit for each test.

2. Air Handling Units - Cooling and Heating Coil Capacity and Control

a. System/Equipment to be Tested: AHU-11 and AHU-12, and their associated control systems.
b. Functions to be Tested: capacity of the heating and cooling coils.
c. Conditions of the Test: the mixed air temperature is equal to the scheduled entering cooling coil condition. Measure and record leaving heating and cooling coil temperatures, humidifier status and output, room temperature and relative humidity for a period of 20 minutes; repeat test while increasing coil entering conditions by 4°F DBT and maintain 40% relative humidity. Monitor and record leaving coil conditions and room conditions (dry and wet bulb), air flow, entering air temperature (dry bulb and wet bulb) valve positions, water flow, air differential pressure, heater water flow, humidifier output, makeup air temperature, fan

horsepower, discharge static pressure, face and bypass damper positions. Test system at 100% 75%, 50% and 25% cooling load. Check dehumidification capacity by increasing space humidity level to 65% and then changing setpoint to 40% while maintaining dry bulb setpoint. Contractor shall provide load during test conditions.

d. Acceptable Results: coils provide the scheduled/submitted capacities at design conditions 100% air flow, and supply air temperature (±0.5°F) and humidity is maintained throughout the test (±2%).

3. Air Handling Units - Humidity Control

a. System/Equipment to be Tested: AHU-11 and AHU-12, and their associated control systems.
b. Functions to be Tested: capacity and control of steam humidifiers.
c. Conditions of the Test: the mixed air temperature is equal to the scheduled entering air condition at humidifiers, set room setpoint to 68°F, 40% RH.; measure and record air flow, leaving heating and cooling coil temperatures (dry bulb and wet bulb); calculate % RH; humidifier status and output, room temperature (dry bulb and wet bulb); calculate relative humidity for a period of 20 minutes. Repeat test while increasing room setpoint in 2°F DBT increments while maintaining 40% relative humidity. Test system up to 78°F, 40% RH. Test high limit alarm by calling for high humidity (with internal source of humidity if necessary).
d. Acceptable Results: coils provide the scheduled/submitted capacities at design conditions 100% air flow, and room setpoint humidity level is maintained within design tolerances. Confirm activation of high limit alarm.

4. Air Handling Units - Automatic Fire Alarm Operation

a. System/Equipment to be Tested: AHU-11 and AHU-12, their associated air distribution and control systems and variable speed drives and fire alarm system. This test shall be performed in conjunction with Division 17800.
b. Functions to be Tested: stopping of supply air fans as per control drawings.
c. Conditions of the Test: begin the test with all the associated fans of the system (as described on the control diagrams) "ON". Activate AHU smoke detector.
d. Acceptable Results: the control system is confirmed. Reset AHU operation. Record events.

5. Air Handling Units - Supply Fan Tracking Control

a. System/Equipment to be Tested: AHU-11 and AHU-12, their associated air distribution and control systems and variable speed drives.
b. Functions to be Tested: modulation of the fan speeds as filter loads build up.

c. Conditions of the Test: begin the test with clean prefilters and final filters; monitor and record pressure drops, supply air volume and fan speed. Reduce face area across each prefilter (cover with card board) until differential pressure equals scheduled "final" pressure condition is achieved; monitor and record pressure drops, air volumes, fan horsepower, discharge static pressure (before and after) and fan speed for 20 minutes.
d. Acceptable Results: The fan speed alters to provide constant air volume. Verify dirty filter alarm.

6. Air Handling Units - Loss of Control Power

a. System/Equipment to be Tested: AHU-11 and AHU-12, and their associated air distribution and control systems.
b. Functions to be Tested: fail safe position of control dampers and valves when control power is lost at panel and the return to normal operation once power is restored.
c. Conditions of the Test: begin the test with all systems operating; disengage control power.
d. Acceptable Results: drives, valves and dampers fail to their "safe" positions. Restore power and monitor their return to "normal".

7. Air Handling Units - Loss of Power

a. System/Equipment to be Tested: AHU-11 and AHU-12 and their associated air distribution and control systems.
b. Functions to be Tested: shutdown of the unit in an emergency power mode and its return to normal operation once power is restored.
c. Conditions of the Test: begin the test with all systems operating; disengage power, switch to emergency power and then restore normal power.
d. Acceptable Results: Unit cycles off, per the control sequence, outside air dampers close; and return to normal operation upon power restoration.

G Electric/Mechanical Room Supply Fans

1. Electric/Mechanical Room Supply Fans - Temperature Control

a. System/Equipment to be Tested: SF-11, SF-12, EF-16, EF-17, and their associated air distribution and control systems.
b. Functions to be Tested: Activation of fans and opening of outside air dampers in order to maintain space temperature setpoint.
c. Conditions of the Test: prior to beginning the test each space shall be heated to 92°F, the outside air temperature shall be 60°F or less. Monitor and record fan

operation, and space temperature for one entire cycle, including; cooling to 70°F, and then rewarming to 90°F. Provide heat source as necessary.

d. Acceptable Results: dampers and fans cycle to control space temperature (±2°F) per the control sequences, confirm alarm condition.

2. Electric/Mechanical Room Supply Fans - Supply Fan/Exhaust Fan Interlock

   a. System/Equipment to be Tested: SF-11, SF-12, EF-16, EF-17, and their associated air distribution and control systems.
   b. Functions to be Tested: confirm interlock function between supply fans and their associated exhaust fans.
   c. Conditions of the Test: begin the test with all the associated fans of the system (as described on the control diagrams) "ON". Repeat test for each fan.
   d. Acceptable Results: the unit confirms the interlock function when each of the fans is individually shut off while the remaining are "ON".

3. Electric/Mechanical Room Supply Fans - Loss of Control Power

   a. System/Equipment to be Tested: SF-11, SF-12, EF-16, EF-17, and their associated air distribution and control systems.
   b. Functions to be Tested: fail safe position of control dampers when control power is lost; and the return to "normal" operation once power is restored.
   c. Conditions of the Test: begin the test with all systems operating; disengage control power.
   d. Acceptable Results: dampers fail to their "safe" positions and return to normal operation upon restoration of power.

4. Electric/Mechanical Room Supply Fans - Loss of Power

   a. System/Equipment to be Tested: SF-11, SF-12, EF-16, EF-17, and their associated air distribution and control systems. This test may be performed in conjunction with other test performed under Division 17.
   b. Functions to be Tested: shutdown of the fans in an emergency power mode and their return to normal operation once power is restored.
   c. Conditions of the Test: begin the test with all systems operating; disengage power, switch to emergency power and then restore normal.
   d. Acceptable Results: Units cycles off and are returned to power per the specified sequence.

H. Chiller Room Supply Fans

1. Chiller Room Supply Fans - Temperature Control

   a. System/Equipment to be Tested: SF-13, EF-8, fan coil unit F-LB.10 and their associated air distribution and control systems.
   b. Functions to be Tested: control of space temperature
   c. Conditions of the Test: prior to beginning the test each space shall be heated to 92°F and outside air temperature is 50°F or more.
   d. Acceptable Results: dampers and fans cycle to control space temperature per the control sequences. Monitor and record fan operation, and space temperature for one entire cycle including cooling to 70°F; and then rewarming to 90°F.

2. Chiller Room Supply Fans - Supply Fan/Exhaust Fan Interlock

   a. System/Equipment to be Tested: SF-13, EF-8 and their associated air distribution and control systems.
   b. Functions to be Tested: confirm interlock function between supply fans and their associated exhaust fans.
   c. Conditions of the Test: begin the test with all the associated fans of the system (as described on the control diagrams) "ON". Shut off each fan in turn by opening disconnect.
   d. Acceptable Results: the unit confirms the interlock function and outside air dampers close when each of the fans is individually shut off while the remaining are "ON". All alarms shall be confirmed.

3. Chiller Room Supply Fans - Loss of Control Power

   a. System/Equipment to be Tested: SF-13, EF-8, and F-LB.10 and their associated air distribution and control systems.
   b. Functions to be Tested: fail safe position of control dampers and valves when control power is lost; and the return to normal operation once power is restored.
   c. Conditions of the Test: begin the test with all systems operating; disengage control power.
   d. Acceptable Results: dampers and valves fail to their "safe" positions and return to normal operation upon restoration of power.

4. Chiller Room Supply Fans - Loss of Power

   a. System/Equipment to be Tested: SF-13, EF-8, and F-LB.10 and their associated air distribution and control systems.

b. Functions to be Tested: shutdown of the fans in an emergency power mode and their return to normal operation once power is restored.
c. Conditions of the Test: begin the test with all systems operating; disengage power.
d. Acceptable Results: Units cycles off and are returned to power per the specified sequence.

I. Fan Coil Units

1. Fan Coil Units - Cooling Coil Capacity

a. System/Equipment to be Tested: all fan coils, their piping air distribution and associated control systems. A random selection of 10% of the boxes shall be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed.
b. Functions to be Tested: capacity of the cooling coils.
c. Conditions of the Test: Provide artificial cooling load to match scheduled capacity, with all supplemental cooling controlled off. Allow fan coil to operate per control sequence. Decrease cooling load by 50%, monitor and record the fan coil operation and room temperature for 20 minutes. Decrease cooling load to 25%, monitor and record the fan coil operation and room temperature for 20 minutes.
d. Acceptable Results: Unit operates per the control sequence and the room is cooled and maintains space setpoint.

2. Fan Coil Units - Loss of Control Power

a. System/Equipment to be Tested: all fan coils, their piping air distribution and associated control systems. A random selection of 10% of the boxes shall be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed.
b. Functions to be Tested: fail safe position of control valves when control power is lost.
c. Conditions of the Test: begin the test with all systems operating; disengage control power.
d. Acceptable Results: valves fail to their "safe" positions per the specifications and return to normal operation upon restoration of power.

3. Fan Coil Units - Loss of Power

   a. System/Equipment to be Tested: all fan coils, their piping air distribution and associated control systems. A random selection of 10% of the boxes shall be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed. This test may be performed in conjunction with tests performed in other areas of Division 17.
   b. Functions to be Tested: shutdown of the units in an emergency power mode and their return to normal operation once power is restored.
   c. Conditions of the Test: begin the test with all systems operating; disengage power.
   d. Acceptable Results: Units cycle off and are returned to power per the specified sequence.

J. Variable Air Volume Boxes

1. Variable Air volume Units - Occupied Cooling Mode

   a. System/Equipment to be Tested: Variable air volume boxes, their associated piping, distribution, and controls. A random selection of 10% of the boxes shall be tested on the first through fourth mezzanine floors. All boxes on the lower and upper basement floors will be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed.
   b. Functions to be Tested: Operation of box during an occupied cooling mode.
   c. Conditions of the Test: Provide heat load to space to match scheduled cooling capacity. Monitor and record primary air flow and primary air and room temperatures for 20 minutes. Test again at 75%, 50% and 25% load.
   d. Acceptable Results: Box operates per the control sequence and the room is cooled to, and maintains, space setpoint ±2°F.

2. Variable Air volume Units - Occupied Heating Mode

   a. System/Equipment to be Tested: Variable air volume boxes, their associated piping, distribution, and controls. A random selection of 10% of the boxes shall be tested on the first through fourth mezzanine floors. All boxes on the lower and upper basement floors will be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed.

b. Functions to be Tested: Modulation of the heating coil control valve, operation of the box primary air.
c. Conditions of the Test: Disengage all other supplemental heating to the space. Provide heating load to match scheduled box heating capacity. Monitor and record operation of primary air flow, heating coil valve position; discharge, primary air, and room temperatures for 20 minutes. Retest with heating load at 75%, 50% and 25%.
d. Acceptable Results: Box operates per the control sequence and the room is heated to and maintains space setpoint ±2°F.

3. Variable Air volume Units - Unoccupied Cooling Mode

a. System/Equipment to be Tested: Variable air volume boxes, their associated piping, distribution, and controls. A random selection of 10% of the boxes shall be tested on the first through fourth mezzanine floors. All boxes on the lower and basement floors will be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed.
b. Functions to be Tested: Operation of box during an unoccupied cooling mode.
c. Conditions of the Test: Disengage all other supplemental cooling to the space. Heat space to 95°F, turn off heat source. Monitor and record primary air flow and primary air and room temperatures. Cool space to setpoint, activate heat source again, cycling box through one entire sequence.
d. Acceptable Results: Box operates per the control sequence and the room is cooled to, and maintains, space setpoint ±2°F.

4. Variable Air volume Units - Unoccupied Heating Mode

a. System/Equipment to be Tested: Variable air volume boxes, their associated piping, distribution, and controls. A random selection of 10% of the boxes shall be tested on the first through fourth mezzanine floors. All boxes on the lower and basement floors will be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed.
b. Functions to be Tested: Modulation of the heating coil control valve, operation of the box primary air flow.
c. Conditions of the Test: Disengage all other supplemental heating to the space. Provide heating load to match scheduled box heating capacity. Monitor and record operation of primary air flow, heating coil valve position; discharge,

primary air, and room temperatures for 20 minutes. Retest with heating load at 75%, 50% and 25%.

d. Acceptable Results: Box operates per the control sequence and the room is heated to and maintains space setpoint ±2° F.

5. Variable Air Volume Units - Control Power Failure

   a. System/Equipment to be Tested: VAV units, their piping, air distribution and associated control systems. A random selection of 10% of the boxes shall be tested on the first through fourth mezzanine floors, all boxes on the lower and basement floors will be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed.
   b. Functions to be Tested: fail safe position of control damper and valves when control power is lost.
   c. Conditions of the Test: begin the test with all systems operating; disengage control power.
   d. Acceptable Results: dampers and valves fail to their "safe" positions per the specifications and return to normal operation upon restoration of power.

6. Variable Air volume Units - Power Failure

   a. System/Equipment to be Tested: vav units, their piping, air distribution and associated control systems. A random selection of 10% of the boxes shall be tested on the first through fourth mezzanine floors, all boxes on the lower and basement floors will be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed.
   b. Functions to be Tested: shutdown of the units in an emergency power mode and their return to normal operation once power is restored.
   c. Conditions of the Test: begin the test with all systems operating; disengage power, switch to emergency power and then restore to normal.
   d. Acceptable Results: Units cycle off and are returned to power per the specified sequence.

K. Fan Powered Variable Air Volume Boxes

1. Fan Powered Variable Air volume Units - Occupied Cooling Mode

    a. System/Equipment to be Tested: Fan powered variable air volume boxes, their associated piping, distribution, and controls. A random selection of 10% of the boxes shall be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed.
    b. Functions to be Tested: Operation of box during an occupied cooling mode.
    c. Conditions of the Test: Provide heat load to match scheduled cooling capacity. Monitor and record operation of fan, primary air flow; primary air and room temperatures for 20 minutes. Retest at 75%, 50% and 25% load.
    d. Acceptable Results: Box operates per the control sequence and the room is cooled to and maintains space setpoint ±2°F.

2. Fan Powered Variable Air volume Units - Unoccupied Cooling Mode

    a. System/Equipment to be Tested: Fan powered variable air volume boxes, their associated piping, distribution, and controls. A random selection of 10% of the boxes shall be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed.
    b. Functions to be Tested: Operation of box during an unoccupied cooling mode.
    c. Conditions of the Test: Disengage all other supplemental cooling to the space. Heat space to 95°F, turn off heat source. Monitor and record primary air flow and primary air and room temperatures. Cool room until unit cycles off. Activate heat load again, putting box through one entire cycle.
    d. Acceptable Results: Box operates per the control sequence and the room is cooled to, and maintains, space setpoint.

3. Fan Powered Variable Air volume Units - Occupied Heating Mode

    a. System/Equipment to be Tested: Fan powered variable air volume boxes, their associated piping, distribution, and controls. A random selection of 10% of the boxes shall be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed.

b. Functions to be Tested: Modulation of the heating coil control valve, operation of the box primary air flow and fan.

c. Conditions of the Test: Disengage all other supplemental heating to the space. Provide cooling source to match scheduled heating capacity. Monitor and record operation of fan, primary air flow, heating coil valve position; discharge, primary air, and room temperatures for 20 minutes. Retest at 75%, 50% and 25% load.

d. Acceptable Results: Box operates per the control sequence and the room is heated to and maintains space setpoint for 20 minutes.

4. Fan Powered Variable Air volume Units - Unoccupied Heating Mode

a. System/Equipment to be Tested: Fan powered variable air volume boxes, their associated piping, distribution, and controls. A random selection of 10% of the boxes shall be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed.

b. Functions to be Tested: Modulation of the heating coil control valve, operation of the box primary air flow and fan.

c. Conditions of the Test: Disengage all other supplemental heating to the space. Provide heating load to match scheduled box heating capacity. Monitor and record operation of primary air flow, heating coil valve position; discharge, primary air, and room temperatures for 20 minutes. Retest with heating load at 75%, 50% and 25%.

d. Acceptable Results: Box operates per the control sequence and the room is heated to and maintains space setpoint ±2°F.

5. Fan Powered Variable Air volume Units - Control Power Failure

a. a. System/Equipment to be Tested: fan powered vav units, their piping, air distribution and associated control systems. A random selection of 10% of the boxes shall be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed.

b. b. Functions to be Tested: fail safe position of control damper, fan and valves when control power is lost.

c. c. Conditions of the Test: begin the test with all systems operating; disengage control power.

d. d. Acceptable Results: fan, dampers and valves fail to their "safe" positions per the specifications and return normal operation with power restoration.

6. Fan Powered Variable Air volume Units - Power Failure

   a. System/Equipment to be Tested: fan powered vav units, their piping, air distribution and associated control systems. A random selection of 10% of the boxes shall be tested. Failure of any randomly selected system in the first set, shall require an additional equally selected quantity to be tested. Failure of any of the second set shall result in all remaining systems to be tested. Retest all failed systems until passed.
   b. Functions to be Tested: shutdown of the units in an emergency power mode and their return to normal operation once power is restored.
   c. Conditions of the Test: begin the test with all systems operating; disengage power, switch to emergency power and then restore to normal.
   d. Acceptable Results: Units cycle off and are returned to power per the specified sequence.

L. Computer Room Units

1. Computer Room Unit - Cooling Capacity

   a. System/Equipment to be Tested: AC-B.1, AC-2.1, AC-3.1, AC-4.1, AC-4.2, AC-4.3, their piping and associated control systems.
   b. Functions to be Tested: Cooling capacity
   c. Conditions of the Test: provide artificial steady state cooling load, monitor and record room temperature for 20 minutes. Retest at 75%, 50% and 25% load.
   d. Acceptable Results: The unit maintains the room setpoint ±2°F.

2. Computer Room Unit - Dehumidification/Reheat Capacity

   a. System/Equipment to be Tested: AC-B.1, AC-2.1, AC-3.1, AC-4.1, AC-4.2, AC-4.3, their piping and associated control systems.
   b. Functions to be Tested: Reheat capacity
   c. Conditions of the Test: provide artificial humidification load, monitor and record room temperature and humidity for 20 minutes.
   d. Acceptable Results: The unit maintains the room setpoint at 100%, 75%, 50%, and 25% load.

3. Computer Room Unit - System Redundancy

   a. System/Equipment to be Tested: AC-4.1, AC-4.2, their piping and associated control systems.
   b. Functions to be Tested: Automatic switchover.

c. Conditions of the Test: Provide a cooling load to the space, AC-4.1 shall be removed from service.
d. Acceptable Results: AC-4.2 automatically switches on when the temperature exceeds the allowable temperature offset and an alarm condition is signaled via the DDC system.

4. Computer Room Unit - Humidification Control

a. System/Equipment to be Tested: AC-B.1, AC-2.1, AC-3.1, AC-4.1, AC-4.2, AC-4.3, their piping and associated control systems.
b. Functions to be Tested: Humidification control
c. Conditions of the Test: Lower room humidity below 40%. Establish for 20 minutes. Reset space setpoint to 50%. Measure rate and time required to return space to preset humidity level of 50%.
d. Acceptable Results: The unit maintains the room relative humidity ±5%. Room RH level of 50% is stable within 15 minutes from initial room condition of 40% RH.

5. Computer Room Unit - Power Failure

a. System/Equipment to be Tested: computer room units, their piping, air distribution and associated control systems. This test may be performed in conjunction with other tests performed under Division 17.
b. Functions to be Tested: shutdown of the units in an emergency power mode and their return to normal operation once power is restored.
c. Conditions of the Test: begin the test with all systems operating; disengage power, switch to emergency and then restore normal power.
d. Acceptable Results: Units cycle off and are returned to power per the specified sequence.

3.6 TEST PROCEDURES

A. Submit for approval detailed FPT procedures corresponding to the FPT criteria in Acceptance Criteria in this Section. FPT procedures shall be detailed test instructions, written with sufficient step-by-step information to allow a test to be repeated under identical conditions. List the value for all setpoints and inputs, positions of adjustable devices and acceptable results for each condition tested. Provide a unique alpha-numeric identification for each FPT procedure.

B. Submit for approval test procedure check-off sheets. Number each test procedure check-off item with the same number as the corresponding FPT procedure.

C. Demonstrate successful execution of FPT's listed under Acceptance Criteria in this Section. Sign-off each successful test and obtain the sign-off of the Commissioning Agent or other Owner-designated witness.

END OF SECTION

Appendix 4-8

SECTION 17520 - COMMISSIONING, EXHAUST AIR SYSTEMS

GUIDE SPECIFICATION

The following guide specification is intended to be modified and included in the construction contract documents. Items to be modified will be decided by consultation involving the owner's project manager and the A/E. The A/E is expected to modify this and other specifications as necessary to accurately reflect commissioning requirements based upon specific systems, conditions, and requirements of the project.

PART 1 - GENERAL

1.1 DESCRIPTION

A. The purpose of this section is to describe the commissioning process specific to the exhaust air systems and equipment.

1.2 RELATED WORK

A. Reference Sections 01650, 17100 and 17110 for primary commissioning requirements and responsibilities.

B. Reference Section 15995 for contractor requirements in support of the commissioning process. Refer to Division 15 specifications and plans and contractor shop drawings for system configuration and details of required construction.

C. Reference Section 17595 for testing, adjusting and balancing (TAB) requirements. TAB shall be substantially complete before performing FPTs required in this section.

PART 2 - PRODUCTS

2.1 TEST EQUIPMENT

A. Refer to Section 17595 for tools and equipment required. The Contractor shall provide all necessary test equipment.

PART 3 - EXECUTION

3.1 CONSTRUCTION OBSERVATION

A. Obtain and review design documents for overall design intent and the overall required systems configurations.

B. Obtain and review shop drawings and submittals for installation criteria and the required construction details, as they support and further define the systems features.

C. The Test Engineer shall make general inspections at the job site and shall review the following for configuration, quality of construction, adherence to design requirements, and conformance with shop drawings and submittal information.

D. The Test Engineer shall provide periodic observations of the HVAC systems equipment, ductwork, and piping systems as constructed. Observations shall commence with arrival of major components on the job site, and continue through the construction phase and into the start-up phases of work. In addition to general observation services, the Test Engineer will specifically observe the following specific system features:

1. Prime Movers/Major Equipment:

    a. Fans:
        1. Conditions of equipment as delivered/installed/ damage/cleanliness
        2. Equipment data/compliance with specifications and shop drawings
        3. Performance curves/configuration per submitted documents
        4. Installation per design documents/plans and specifications
        5. Equipment mounting and anchoring devices
        6. Vibration isolation devices

2. Accessories/Exhaust Air Systems:

    a. Balancing dampers/fit and integrity/locking quadrants
    b. Fire dampers/fit and integrity/fusible links
    c. Control dampers/fit and integrity/seals/linkage/motor mounting
    d. Smoke dampers/fit and integrity/linkage motor mounting
    e. Isolation dampers/fit and integrity/seals/linkage/motor mounting.

3. Distribution Systems/Ductwork:

    a. Size and configuration
    b. Fittings/transitions and takeoffs
    c. Seams and joints/integrity and sealing
    d. Hangers and bracing
    e. Flexible connections
    f. Sealing/sealers and joints
    g. Thickness per specifications/SMACNA standards
    h. Lining (if applicable) per SMACNA standards

4. Terminal Units:

   a. Air Terminal/Boxes:
      1. Number, size configuration per plans and specifications
      2. Balance dampers (if applicable)
      3. Controls components and configurations
      4. Entrance and exit conditions per requirements
      5. Sound attenuation per plans and specifications
      6. Entrance conditions to box/length of straight runs

3.2 CLEANING

A. Test Engineer and Commissioning Agent shall witness and verify. See Division 15 requirements.

3.3 TESTS

A. Test Engineer and Commissioning Agent shall witness and verify. See Division 15 requirements.

3.4 EQUIPMENT SAFETY DEVICE CHECKS

A. Insure interlocks operate per design requirements.

B. The majority of mechanical equipment requires integral safety devices to stop/prevent equipment operation unless minimum safety standards or conditions are met. This could include supply fan interlocks, fume hood exhaust fan interlocks, proof-of-flow, etc. The Test Engineer must observe the actual performance of safety shutoffs in a real or closely-simulated condition of failure.

C. Systems may include safety devices and components that control a variety of equipment operating as a system. Interlocks may be hardwired or installed via software. These interlocks shall also be verified by the Test Engineer. Refer to design documents for required interlocks and test each as required.

3.5 ACCEPTANCE CRITERIA

A. Demonstrate to the Owner's Representative successful execution of the following FPTs (functional performance tests) in accordance with approved FPT procedures as described in Test Procedures in this Section:

B. EXHAUST VARIABLE AIR VOLUME UNITS (EVAV)

1. Exhaust Variable Air Volume Boxes - Tracking of Supply air

a. System/Equipment to be Tested: Exhaust variable air volume boxes, their associated supply air systems, controls, snorkel exhaust systems, laboratory exhaust and fume hoods.
b. Functions to be tested: Differential air flows are maintained within individual laboratories.
c. Conditions of the Test: All air systems within the space being tested are operational, doors to the space are closed, monitor and record operation of air flow from the all EVAV, VAV within the laboratory for 20 minutes during both occupied and unoccupied modes.
d. Acceptable Results: Differential air flows are maintained within the space proven by a smoke bomb. Pressure relationships are maintained within individual laboratories.

2. Exhaust Variable Air Volume Units - Control Power Failure

a. System/Equipment to be Tested: exhaust and supply vav units, air distribution and associated control systems. All exhaust VAV boxes shall be tested.
b. Functions to be tested: fail safe position of control dampers when control power is lost.
c. Conditions of the Test: begin the test with all systems operating; disengage control power.
d. Acceptable Results: dampers fail to their "safe" positions per the specifications and return to their normal operating mode when power is restored.

C. FUME HOOD EXHAUST FANS

1. Fume Hood Exhaust Fans - Backup

a. System/Equipment to be Tested: EF-18, EF-19, EF-20 and EF-21, and their associated air distribution and control systems. Each fan shall be tested in the "lead" position.
b. Functions to be tested: Automatic switch over of backup fans.
c. Conditions of the Test: The "lead" shall be operation. Power to the lead shall be disrupted at disconnect.
d. Acceptable Results: The fans operate per the control sequence and all alarm conditions are confirmed.

2. Fume Hood Exhaust Fans - Control Power Failure

a. System/Equipment to be Tested: EF-18, EF-19, EF-20 and EF-21, air distribution and associated control systems. Each fan shall be tested.

b. Functions to be tested: fail safe position of control dampers, operation of fans when control power is lost.
c. Conditions of the Test: begin the test with all systems operating; disengage control power.
d. Acceptable Results: dampers fail to their "safe" positions and fans operate per the specifications.

3. Fume Hood Exhaust Fans - Power Failure

   a. System/Equipment to be Tested: EF-18, EF-19, EF-20 and EF-21 and their associated air distribution and control systems.
   b. Functions to be tested: operation of the fans in an emergency power mode and continuation of operation once power is restored.
   c. Conditions of the Test: begin the test with all systems operating; disengage power.
   d. Acceptable Results: "Lead" fan stays on.

D. SNORKEL EXHAUST FANS

1. Snorkel Exhaust Fans - Control Power Failure

   a. System/Equipment to be Tested: EF-1, EF-3, and EF-5, air distribution and associated control systems.
   b. Functions to be tested: operation of fans when control power is lost.
   c. Conditions of the Test: begin the test with all systems operating; disengage control power.
   d. Acceptable Results: fans operate per the specifications.

2. Snorkel Exhaust Fans - Power Failure

   a. System/Equipment to be Tested: EF-1, EF-3, and EF-5 and their associated air distribution and control systems. Each fan shall be tested.
   b. Functions to be tested: operation of the fans in an emergency power mode and their return to operation once power is restored.
   c. Conditions of the Test: begin the test with all systems operating; disengage power switch to emergency and then restore normal power.
   d. Acceptable Results: Fan returns to operation per the specifications.

E. TOILET EXHAUST FANS

1. Toilet Exhaust Fans - Control Power Failure

a. System/Equipment to be Tested: EF-24, EF-25, EF-26 and EF-27, air distribution and associated control systems.
b. Functions to be tested: operation of fans when control power is lost.
c. Conditions of the Test: begin the test with all systems operating; disengage control power.
d. Acceptable Results: fans operate per the specifications.

2. Toilet Exhaust Fans - Power Failure

a. System/Equipment to be Tested: EF-24, EF-25, EF-26 and EF-27 and their associated air distribution and control systems.
b. Functions to be tested: fan shutdown in an emergency power mode and their return to operation once power is restored.
c. Conditions of the Test: begin the test with all systems operating, disengage power.
d. Acceptable Results: Fans return to operation per the specifications.

F. PAINT BOOTH EXHAUST FAN

1. Paint Booth Exhaust Fan - Interlocks

a. System/Equipment to be Tested: EF-9, all air distribution serving room 076, the paint booth and control systems.
b. Functions to be tested: Air balance within the shop is maintained.
c. Conditions of the Test: The fan shall be switched on at the paint booth. Monitor and record supply and exhaust air flows to the space, and fan status for 20 minutes. Repeat test "switching" fan off.
d. Acceptable Results: The fan and boxes operate according to the control sequences and maintain the differential air flow.

2. Paint Booth Exhaust Fan - Paint Booth Alarm

a. System/Equipment to be Tested: EF-9, all air distribution serving room 076, the paint booth and control systems.
b. Functions to be tested: Local alarm condition when fan is dysfunctional.
c. Conditions of the Test: The fan shall be switched on at the paint booth. Monitor and record supply and exhaust air flows to the space, disconnect power to fan at disconnect.
d. Acceptable Results: A system and local alarm are initiated by the DDC system.

3. Paint Booth Exhaust Fan - Control Power Failure

   a. System/Equipment to be Tested: EF-9, all air distribution serving room 076, the paint booth and control systems and the paint booth.
   b. Functions to be tested: operation of the fan when control power is lost.
   c. Conditions of the Test: begin the test with all systems operating; disengage control power.
   d. Acceptable Results: fan operates per the specifications.

4. Paint Booth Exhaust Fan - Power Failure

   a. System/Equipment to be Tested: EF-9, all air distribution serving room 076, the paint booth and control systems and the paint booth. This test may be performed in conjunction with other tests performed under Division 17.
   b. Functions to be tested: shut down of the fan in an emergency power mode and return to operation once power is restored.
   c. Conditions of the Test: begin the test with all systems operating; disengage power, switch to emergency and then restore normal power.
   d. Acceptable Results: the fan shuts down and then returns to normal operation.

G. CHILLER ROOM EXHAUST FAN

1. Chiller Room Exhaust Fan - Temperature Control: See Section 17510.

2. Chiller Room Exhaust Fan - Oxygen Level Alarm

   a. System/Equipment to be Tested: EF-8 and its associated air distribution and control systems for phase 1; EF-8 and SF-13 and there associated air distribution and control systems for phase 2. This test shall be performed during the completion of phase I and again in phase II.
   b. Functions to be tested: Activation of exhaust fan upon sensing a low oxygen level.
   c. Conditions of the Test: Provide a low oxygen level (19.5%) at the sensor. Do NOT subject the room to a low oxygen condition.
   d. Acceptable Results: For Phase 1, the fan, dampers shall operate, and alarm conditions shall be initiated per the control sequences. For Phase 2, both fans, dampers shall operate, and alarm conditions shall be initiated per the control sequences. Confirm keyed alarm switch operation and time delay, confirm activation sequence by manual switch. The system shall be tested during Phase 1 and Phase 2.

3. Chiller Room Exhaust Fan - Control Power Failure

   a. System/Equipment to be Tested: EF-8 and its associated air distribution and control systems for phase 1; EF-8 and SF-13 and there associated air distribution and control systems for phase 2. This test shall be performed during the completion of phase I and again in phase II. These tests may be performed in conjunction with Section 17510.
   b. Functions to be tested: operation of fans, control dampers when control power is lost.
   c. Conditions of the Test: begin the test with all systems operating; disengage control power.
   d. Acceptable Results: dampers and fans operates per the specifications.

4. Chiller Room Exhaust Fan - Power Failure

   a. System/Equipment to be Tested: EF-8 and its associated air distribution and control systems for phase 1; EF-8 and SF-13 and there associated air distribution and control systems for phase 2. This test shall be performed during the completion of phase I and again in phase II. These tests may be performed in conjunction with Section 17510 and other Sections of Division 17.
   b. Functions to be tested: shut down of the fans in an emergency power mode and their return to operation once power is restored.
   c. Conditions of the Test: begin the test with all systems operating; disengage power, switch to emergency and then restore power to normal.
   d. Acceptable Results: Fans return to operation per the control sequence.

H. LOADING DOCK EXHAUST FAN

1. Loading Dock Exhaust Fan - Operation

   a. System/Equipment to be Tested: EF-7 and its associated air distribution and control systems.
   b. Functions to be tested: operation of the fan.
   c. Conditions of the Test: provide localized high carbon monoxide level at sensor (40 ppm).
   d. Acceptable Results: Fan operates per the control sequence. When manual switch is initiated the fan operates per the control sequence.

2. Loading Dock Exhaust Fan - Control Power Failure

   a. System/Equipment to be Tested: EF-7 air distribution and associated control systems.
   b. Functions to be tested: operation of the fan when control power is lost.
   c. Conditions of the Test: begin the test with all systems operating; disengage control power.

d. Acceptable Results: fan operates per the specifications.

3. Loading Dock Exhaust Fan - Power Failure

   a. System/Equipment to be Tested: EF-8 and its associated air distribution and control systems.
   b. Functions to be tested: shut down of the fan in an emergency power mode and return to operation once power is restored.
   c. Conditions of the Test: begin the test with all systems operating; disengage power.
   d. Acceptable Results: Fan returns to operation per the control sequence.

3.6 TEST PROCEDURES

A. Submit for approval detailed FPT procedures corresponding to the FPT criteria in Acceptance Criteria in this Section. FPT procedures shall be detailed test instructions, written with sufficient step-by-step information to allow a test to be repeated under identical conditions. List the value for all setpoints and inputs, positions of adjustable devices and acceptable results for each condition tested. Provide a unique alpha-numeric identification for each FPT procedure.

B. Submit for approval test procedure check-off sheets. Number each test procedure check-off item with the same number as the corresponding FPT procedure.

C. Demonstrate successful execution of FPT's listed under Acceptance Criteria in this Section. Sign-off each successful test and obtain the sign-off of the Commissioning Agent or other Owner-designated witness.

END OF SECTION

Appendix 4-9

SECTION 17530 - COMMISSIONING, HOT WATER HEATING SYSTEMS

GUIDE SPECIFICATION

The following guide specification is intended to be modified and included in the construction contract documents. Items to be modified will be decided by consultation involving the owner's project manager and the A/E. The A/E is expected to modify this and other specifications as necessary to accurately reflect commissioning requirements based upon specific systems, conditions, and requirements of the project.

PART 1 - GENERAL

1.1 DESCRIPTION

A. The purpose of this section is to describe the commissioning process specific to the hot water heating systems and equipment.

1.2 RELATED WORK

A. Reference Sections 01650, 17100 and 17110 for primary commissioning requirements and responsibilities.

B. Reference Section 15995 for contractor requirements in support of the commissioning process. Refer to Division 15 specifications and plans and contractor shop drawings for system configuration and details of required construction.

C. Reference Section 17595 for testing, adjusting and balancing (TAB) requirements. TAB shall be substantially complete before performing FPTs required in this section.

PART 2 - PRODUCTS

2.1 TEST EQUIPMENT

A. Refer to Section 17595 for tools and equipment required.

2.2 TEST EQUIPMENT

A. Submit for approval safety device check procedures in accord with manufacturers' recommended start-up instructions.

PART 3- EXECUTION

3.1 CONSTRUCTION OBSERVATION

A. Obtain and review design documents for overall design intent and the overall required systems configurations.

B. Obtain and review shop drawings and submittals for installation criteria and the required construction details, as they support and further define the systems features.

C. The Test Engineer shall make general inspections at the job site and shall review the following for configuration, quality of construction, adherence to design requirements, and conformance with shop drawings and submittal information.

3.2 CLEANING

A. Witness and verify cleaning as described by Section 15700, Part 3.

3.3. TESTS

A. Piping System Leak Tests: Witness and verify pressure testing as described by Section 15700, Part 3.

3.4 EQUIPMENT SAFETY DEVICE CHECKS

A. To be determined by the Test Engineer.

3.5 ACCEPTANCE CRITERIA

A. The primary purpose of this section is to witness and verify all of the sequence of operations of the Heating Hot Water Control Diagram shown on sheet M9.5 and additionally called for in the specification section 15700 of the contract documents.

B. Each function and test shall be performed under conditions which simulate as close to an actual operating condition as possible. To that end the contractor shall provide all necessary materials and temporary system modifications to simulate flows, pressures and temperatures necessary to false load the system being tested in order to prove and verify proper operation. Reliance on simulated signals from the DDC system or other indirect indicators is not acceptable. At satisfactory completion of all verified tests, the building system being tested shall be returned to the condition required by the contract documents as a complete and operational system.

C. Demonstrate to the Owner's Representative successful execution of the following FPT's (functional performance tests) in accordance with approved FPT procedures as described in Test Procedures in this Section:

1. Primary Hot Water Loop:
    a. System / Equipment to be Tested:
        1. Primary hot water pumps, HWP-1 & HWP-2.
        2. Heat Exchangers, HX-4 & HX-5.
        3. Associated controls.
    b. Functions to be Tested:
        1. Pump sequencing upon failure of lead pump.
        2. Converter heat exchanger capacity at full load and steam control valve sequencing as load varies.
        3. Pressure and Temperature monitoring.
        4. Loss of control power: fail safe position of valves when control power is lost, and return to normal operation once power is restored.
    c. Conditions of the Test:
        1. With HWP-1 operating as the lead pump, open the lead pump electrical disconnect.
            a. Repeat test with HWP-2 operating as the lead pump.
        2. Perform converter test when atmospheric conditions are sufficient to provide a full heating load via 100% outside air (50°F or lower). Alternately, provide a false load source and temporary connections to the hot water heating system.
            a. Control hot water flow through the converter to a constant flow (± 1 gpm) throughout the test.
            b. Gradually increase converter load from 0% to 100% while observing the steam valve sequencing.
            c. Control converter load at 100% to maintain stable hot water temperatures entering and leaving the converter for 15 minutes. Water temperatures shall be constant within ± 1°F during the stable test period.
            d. Gradually decrease converter load from 100% to 0% while observing the steam valve sequencing.
            e. Steam shall be provided through specified control valves. Bypass valves shall be closed. During the full load portion of the test, steam control valves may be commanded to a fixed position for stability, but shall not be manually positioned by overriding or disconnecting the control actuator.
        3. Demonstrate and Verify the follow monitoring points are accurately being read (feedback of position matches observed position) of by the DDC system. Vary system temperature, pressure, and flows to allow monitoring point to experience full range of signal (minimum to maximum in 10% increments).
            a. Steam PRV valve position, CV-51. Demonstrate CV-51 control valve as the lead control valve.

b. Steam PRV valve position, CV-52. Demonstrate the CV-52 control valve becoming the lead control valve when the load exceeds the capacity of CV-51 and that CV-51 is closed. Demonstrate CV-52 control valve in the full open position (fully loaded) and CV-51 valve modulate to maintain the hot water temperature, TS-51.

c. Demonstrate and verify both CV-5 and CV-52 steam control valves provide discharge water temperature based on the reset schedule called for. Demonstration shall be for both the full range of outside air temperature and water temperature.

d. Valve Position, CV-53, full range of modulation controlled by Temperature Sensor, TS-51.

e. Valve Position, CV-54, full range of modulation controlled by Temperature Sensor, TS-51.

f. Steam Pressure entering building, P-51

g. Steam Pressure leaving PRV, P-52

4. Alarm Conditions, Demonstrate:

a. Failure of the lead pump.

b. Failure to maintain water temperature within 2°F of setpoint.

c. HX-4 has failed, HX-5 is attempting to maintain set point and has also failed.

5. Loss of control power:

a. Begin the test with all systems operating with a 50% load on system, disengage control power.

d. Acceptable Results:

1. Primary pumps, HWP-1 operates as the lead pump. Failure of HWP-1 to operate results in HWP-2 to automatically assume the lead pump position.

2. Same as above only roles of HWP-1 & HWP-2 are reversed.

3. Converters HX-4 & HX-5 maintain leaving water temperature required over entire range of reset schedule from minimal load to maximum load and back to minimal load.

4. All control valves, temperature sensors and pressure sensors function per design parameters. DDC accurately reads (± 0.5% of independently measured reading) each monitoring point over full range of test. Verify with print out for each monitoring point at each 10% increment.

5. Loss of control power: valves fail to their "safe" positions. Once power is restored, automatic control resumes and all control functions required by the sequence of operations are verified.

2. Secondary VAV Hot Water Coil Loop:

a. System / Equipment to be tested:

1. Secondary hot water pumps, HWP-3 & HWP-4.

2. Heat Exchanger, HX-1.

   3. Associated controls.

b. Functions to be tested:
   1. Pump Sequencing.
   2. Heat Exchanger, HX-1, Control valve sequencing as load varies.
   3. Temperature control of water.
   4. Pressure and Temperature monitoring.
   5. Pressure differential control.
   6. Loss of Control Power: Fail safe position of valves when control power is lost, and return to normal operation once power is restored.

c. Conditions of Test:
   1. With HWP-3 operating as the lead pump, open the lead pump electrical disconnect.
      a. Repeat test with HWP-4 operating as the lead pump.
   2. Vary the water temperature supplied to three way control valve CV-55 from 85°F to 140°F.
   3. Simulate the following conditions:
      a. Initial outside air temperature below 60°F.
      b. Increase the outside air temperature between 60°F and 79°F.
      c. Increase the outside air temperature above 80°F.
   4. Vary heating load to all VAV boxes from 10% flow to 100% flow in 10% increments.
   5. Alarm Conditions, Demonstrate:
      a. Failure of the lead pump for each pump.
      b. Failure to maintain water temperature within 2°F.

   6. Loss of control power:
      a. Begin the test with all systems operating with a 50% load on system, disengage control power.

d. Acceptable Results:
   1. Secondary pump, HWP-3 operates as the lead pump. Failure of HWP-3 to operate results in HWP-4 to automatically assume the lead pump position.
   2. Same as above only roles of HWP-3 & HWP-4 are reversed.
   3. Converter, HX-1 maintains leaving water temperature required over entire range of reset schedule from minimal load to maximum load and back to minimal load.
   4. Variable speed drive modulates pump speed to maintain differential pressure, (DP-51) set point.
   5. Pumps are off above 80°F outside air temperature.
   6. All control valves, temperature sensors and pressure sensors function per design parameters. DDC accurately reads (± 0.5% of independently measured reading) each monitoring point over full range of test. Verify with print out for each monitoring point at each 10% increment.

7. Outside air reset schedule is verified by actual system demonstration, (minimum to maximum, back to minimum), outside air temperature and heating water temperature.
8. Loss of Control Power: Valves fail to their "safe" positions. Once power is restored, automatic control resumes and all control functions required by the sequence of operations are verified.

3. Secondary Hot Water Convection Units:

   a. System / Equipment to be tested:
      1. Secondary hot water pumps, HWP-5 & HWP-6
      2. Associated controls.

   b. Functions to be tested:
      1. Pump Sequencing.
      2. Pressure and Temperature monitoring.
      3. Pressure and temperature control.
      4. Loss of Control Power: Fail safe position of valves when control power is lost, and return to normal operation once power is restored.

   c. Conditions of Test:
      1. With HWP-5 operating as the lead pump, open the lead pump electrical disconnect.
         a. Repeat test with HWP-6 operating as the lead pump.
      2. Vary the water temperature supplied to three way control valve CV-59 from 90°F to 180°F
      3. Simulate the following conditions:
         a. Initial outside air temperature below 22°F.
         b. Increase the outside air temperature between 22°F and 60°F.
         c. Increase the outside air temperature between 60°F and 70°F.
         d. Increase the outside air temperature above 70°F.
      4. Alarm Conditions, Demonstrate:
         a. Failure of the lead pump.
         b. Failure to maintain water temperature within 2°F.
      5. Loss of Control Power:
         a. Begin the test with all systems operating with a 50% load on system, disengage control power.

   d. Acceptable Results:
      1. Secondary pump, HWP-5 operates as the lead pump. Failure of HWP-5 to operate results in HWP-6 to automatically assume the lead pump position.
      2. Same as above only roles of HWP-5 & HWP-6 are reversed.
      3. Three way control valve, CV-59 maintains leaving water temperature required over entire range of reset schedule from minimal load to maximum load and back to minimal load
      4. Pumps are off above 70°F outside air temperature.

5. All control valves, temperature sensors and pressure sensors function per design parameters. DDC accurately reads (± 0.5% of independently measured reading) each monitoring point over full range of test. Verify with print out for each monitoring point at each 10% increment.
6. Outside air reset schedule is verified by actual system demonstration, (minimum to maximum, back to minimum), outside air temperature and heating water temperature.
7. Loss of Control Power: Valves fail to their "safe" positions. Once power is restored, automatic control resumes and all control functions required by the sequence of operations are verified.

4. Secondary Heat Pump Heat Exchange Loop:

   a. System / Equipment to be tested:
      1. Secondary hot water pumps, HWP-7 & HWP-8.
      2. Heat Exchanger, HX-6.
      3. Associated controls.
   b. Functions to be tested:
      1. Pump Sequencing.
      2. Heat Exchanger, HX-6, control valve sequencing as load is varied.
      3. Pressure and temperature control
      4. Pressure and temperature monitoring.
      5. Loss of Control Power: Fail safe position of valves when control power is lost with 50% load on system, and return to normal operation once power is restored.
   c. Conditions of Test:
      1. With HWP-7 operating as the lead pump, open the lead pump electrical disconnect.
         a. Repeat test with HWP-8 operating as the lead pump.
      2. Vary the water temperature supplied to three way control valve CV-60 from 140°F to 180°F.
      3. Simulate the Following Conditions:
         a. Inlet temperature to Heat Exchanger, HX-6, below 70°F (TS-92).
         b. Inlet temperature to Heat Exchanger, HX-6, above 70°F (TS-92).
         c. Vary the inlet water temperature to the three way control valve, CV-60, from 140°F to 180°F.
      4. Alarm Conditions, Demonstrate:
         a. Failure of the lead pump for each pump.
         b. Failure to maintain water temperature within 2°F.
      5. Loss of control power:
         a. Begin the test with all systems operating at a 50% level (load), disengage control power.

d. Acceptable Results:
  1. Secondary pump, HWP-7 operates as the lead pump. Failure of HWP-7 to operate results in HWP-8 to automatically assume the lead pump position.
  2. Same as above only roles of HWP-7 & HWP-8 are reversed.
  3. Three way control valve, CV-60 maintains leaving water temperature of 140°F as incoming water temperature to three way control valve, CV-60 is varied from 140°F to 180°F.
  4. Pumps are off when incoming water temperature to heat exchanger, HX-6 is above 72°F, (TS-92).
  5. All control valves, temperature sensors and pressure sensors function per design parameters. DDC accurately reads (± 0.5% of independently measured reading) each monitoring point over full range of test. Verify with print out for each monitoring point at each 10% increment.
  6. Loss of Control Power: Valves fail to their "safe" positions. Once power is restored, automatic control resumes and all control functions required by the sequence of operations are verified.

5. Secondary Convection Unit Hot Water Coil Loop, (Existing Building, EEB):

a. System / Equipment to be tested:
  1. Secondary hot water pumps, HWP-9 & HWP-10
  2. Associated controls.

b. Functions to be tested:
  1. Pump Sequencing.
  2. Pressure and temperature monitoring.
  3. Pressure and temperature control.
  4. Loss of Control Power: Fail safe position of valves when control power is lost with 50% load on system, and return to normal operation once power is restored.

c. Conditions of Test:
  1. With HWP-9 operating as the lead pump, open the lead pump electrical disconnect.
     a. Repeat test with HWP-10 operating as the lead pump.
  2. Vary the water temperature supplied to three way control valve CV-61 from 100°F to 180°F.
  3. Simulate the following conditions:
     a. Initial outside air temperature below 22°F.
     b. Increase the outside air temperature from 60°F to 70°F.
     c. Increase the outside air temperature above 70°F.
  4. Alarm Conditions, Demonstrate:
     a. Failure of the lead pump for each pump.
     b. Failure to maintain water temperature within 2°F.
  5. Loss of control power:
     a. Begin the test with all systems operating, disengage control power.

d. Acceptable Results:
   1. Secondary pump, HWP-9 operates as the lead pump. Failure of HWP-9 to operate results in HWP-10 to automatically assume the lead pump position.
   2. Same as above only roles of HWP-9 & HWP-10 are reversed.
   3. Three way control valve, CV-61 maintains leaving water temperature required over entire range of reset schedule from minimal load to maximum load and back to minimal load
   4. Pumps are off above 70°F. outside air temperature.
   5. All control valves, temperature sensors and pressure sensors function per design parameters. DDC accurately reads each monitoring point over full range of test. Verify with print out for each monitoring point at each 10% increment.
   6. Outside air reset schedule is verified by actual system demonstration, (minimum to maximum, back to minimum), outside air temperature and heating water temperature.
   7. Loss of Control Power: Valves fail to their "safe" positions. Once power is restored, automatic control resumes and all control functions required by the sequence of operations are verified.

6. Secondary Air Conditioning Unit Hot Water Coil Loop:

a. System / Equipment to be tested:
   1. Secondary hot water pumps, HWP-11 & HWP-12
   2. Associated Controls.

b. Functions to be tested:
   1. Pump Sequencing.
   2. Pressure and temperature monitoring.
   3. Pressure and temperature control.
   4. Loss of Control Power: Fail safe position of valves when control power is lost with 50% load on system, and return to normal operation once power is restored.
   5. Pressure differential control.

c. Conditions of Test:
   1. With HWP-11 operating as the lead pump, open the lead pump electrical disconnect.
      a. Repeat test with HWP-12 operating as the lead pump.
   2. Vary the water temperature supplied to three way control valve CV-62 from 120°F to 180°F.
   3. Simulate the following conditions:
      a. Initial outside air temperature below 22°F.
      b. Increase the outside air temperature from 60°F to 70°F.
      c. Increase the outside air temperature above 70°F.

        4. Vary water flow to air conditioning units served by HWP-11 & HWP-12 from 10% flow to 100% flow, in 10% increments. Do for both pumps as the lead pump.
        5. Alarm Conditions, Demonstrate:
            a. Failure of the lead pump for each pump.
            b. Failure to maintain water temperature within 2°F.
        6. Loss of Control Power:
            a. Begin the test with all systems operating, disengage control power with 50% load on system.
    d. Acceptable Results:
        1. Secondary pump, HWP-11 operates as the lead pump. Failure of HWP-11 to operate results in HWP-12 to automatically assume the lead pump position.
        2. Same as above only roles of HWP-11 & HWP-12 are reversed.
        3. Three way control valve, CV-62 maintains leaving water temperature required over entire range of reset schedule from minimal load to maximum load and back to minimal load
        4. Variable speed drive modulates pump speed to maintain differential pressure, (DP-54), set point.
        5. All control valves, temperature sensors and pressure sensors function per design parameters. DDC accurately reads (± 0.5% of independently measured reading) each monitoring point over full range of test. Verify with print out for each monitoring point at each 10% increment.
        6. Outside air reset schedule is verified by actual system demonstration, (minimum to maximum, back to minimum), outside air temperature and heating water temperature.
        7. Loss of Control Power: Valves fail to their "safe" positions. Once power is restored, automatic control resumes and all control functions required by the sequence of operations are verified.

7. Secondary Air Handling Unit Hot Water Coil Loop:

    a. System / Equipment to be tested:
        1. Secondary hot water pumps, HWP-13 & HWP-14
        2. Associated controls.
    b. Functions to be Tested:
        1. Pump Sequencing.
        2. Pressure and temperature monitoring.
        3. Pressure and temperature control.
        4. Loss of control power: fail safe position of valves when control power is lost with 50% load on system, and return to normal operation once power is restored.
    c. Conditions of Test:
        1. With HWP-13 operating as the lead pump, open the lead pump electrical disconnect.

   - a. Repeat test with HWP-14 operating as the lead pump.
  2. Vary the water temperature supplied to three way control valve CV-63 from 120°F to 180°F.
  3. Simulate the Following Conditions:
     - a. Initial outside air temperature below 22°F.
     - b. Increase the outside air temperature to 50°F.
     - c. Increase the outside air temperature above 50°F.
  4. Vary water flow to air conditioning units served by HWP-13 & HWP-14 from 10% flow to 100% flow, in 10% increments. Do for both pumps as the lead pump.
  5. Alarm Conditions, Demonstrate:
     - a. Failure of the lead pump for each pump.
     - b. Failure to maintain water temperature within 2°F.
  6. Loss of Control Power:
     - a. Begin the test with all systems operating with 50% load on system, disengage control power.

- d. Acceptable Results:
  1. Secondary pump, HWP-13 operates as the lead pump. Failure of HWP-13 to operate results in HWP-14 to automatically assume the lead pump position.
  2. Same as above only roles of HWP-13 & HWP-14 are reversed.
  3. Three way control valve, CV-63 maintains leaving water temperature required over entire range of reset schedule from minimal load to maximum load and back to minimal load, ± 2°F.
  4. Variable speed drive modulates pump speed to maintain differential pressure, (DP-55), set point.
  5. All control valves, temperature sensors and pressure sensors function per design parameters. DDC accurately reads (± 0.5% of independently measured reading) each monitoring point over full range of test. Verify with print out for each monitoring point at each 10% increment.
  6. Outside air reset schedule is verified by actual system demonstration, (minimum to maximum, back to minimum), outside air temperature and heating water temperature.
  7. Loss of control power: valves fail to their "safe" positions. Once power is restored, automatic control resumes and all control functions required by the sequence of operations are verified.

8. Cabinet Heaters, Convectors, & Finned Tube Radiation:

- a. System to be Tested: All cabinet heaters, Convectors, and Finned Tube Radiation, their piping, and associated control systems.
- b. Functions to be Tested: Capacity of the heating units.
- c. Conditions of the Test:

   1. Provide artificial cooling load to space which simulates an outside design condition of 24°F. based on a calculated heat loss for all exterior surfaces of space being tested. Monitor and record room temperature for 20 minutes.
   2. Provide artificial heating load to space which simulates an outside design condition of 72°F based on a calculated heat gain for all exterior surfaces of space being tested. Monitor and record room temperature for 20 minutes.

d. Acceptable Results: The unit maintains the room set point at 100%, 75%, 50%, and 25% heating (heat loss) load. When temperature outside is above 72°F, control valve to unit is shut off.

3.6 TEST PROCEDURES

A. Submit for approval detailed FPT procedures corresponding to the FPT criteria in Acceptance Criteria in this Section. FPT procedures shall be detailed test instructions, written with sufficient step-by-step information to allow a test to be repeated under identical conditions. List the value for all setpoints and inputs, positions of adjustable devices and acceptable results for each condition tested. Provide a unique alpha-numeric identification for each FPT procedure.

B. Submit for approval test procedure check-off sheets. Number each test procedure check-off item with the same number as the corresponding FPT procedure.

C. Demonstrate successful execution of FPT's listed under Acceptance Criteria in this Section. Sign-off each successful test and obtain the sign-off of the Commissioning Agent or other Owner-designated witness.

END OF SECTION

Appendix 4-10

SECTION 17540 - COMMISSIONING CHILLED WATER SYSTEMS

GUIDE SPECIFICATION

The following guide specification is intended to be modified and included in the construction contract documents. Items to be modified will be decided by consultation involving the owner's project manager and the A/E. The A/E is expected to modify this and other specifications as necessary to accurately reflect commissioning requirements based upon specific systems, conditions, and requirements of the project.

PART 1 - GENERAL

1.1 DESCRIPTION

A. The purpose of this section is to describe the commissioning process specific to the process chilled water system and equipment.

1.2 RELATED WORK

A. Reference Sections 01650, 17100 and 17110 for primary commissioning requirements and responsibilities.

B. Reference Section 15995 for contractor requirements in support of the commissioning process. Refer to Division 15 specifications and plans and contractor shop drawings for system configuration and details of required construction.

C. Reference Section 17595 for testing, adjusting and balancing (TAB) requirements. TAB shall be substantially complete before performing FPTs required in this section.

PART 2 - PRODUCT

2.1 TEST EQUIPMENT

A. The Contractor shall provide all necessary test equipment.

PART 3 - EXECUTION

3.1 CONSTRUCTION OBSERVATION

A. Obtain and review design documents for overall design intent and the overall required systems configurations.

B. Obtain and review shop drawings and submittals for installation criteria and the required construction details, as they support and further define the systems features.

C. Make general inspections at the job site and review the following for configuration, quality of construction, adherence to design requirements, and conformance with shop drawings and submittal information.

1. Risers: Support, proper fittings, sizes and materials.

2. Lateral lines: Support fittings, materials and sizes.

3. Heat exchanger: Proper piping connections, gasket integrity, plate and frame torque, settings.

4. Cooling tower: Condition and installation per design documents.

D. Each system and all components shall be installed per construction documents, or per approved changes and in accordance with the redline drawings.

3.2 CLEANING

A. Witness and verify cleaning as described by Section 15715, PART 3.

3.3 TESTS

A. Piping System Leak Tests:

1. Witness and verify pressure testing as described by Section 15715, PART 3.

B. Chiller Performance Tests for Each Chiller:

1. After chiller condenser and chilled water flow rate has been set, observe and note differential pressure across evaporation and condenser sections. Verify correct flow rate with manufacturers' specifications/shop drawings.

2. Observe chiller performance under full load conditions, noting entering and leaving chilled water and condenser water temperatures. Obtain motor amperage and power factor readings to calculate actual chiller kw usage. Calculate chiller efficiency in terms of kw per ton of cooling.

3. Observe chiller startup under low load, low condenser water temperature conditions. Compressor surge should not be apparent.

4. Set manual capacity control settings and measure limited motor performance by comparing actual kw usage to full load usage in comparison to percent of load limiting. Test at 15, 50, 75, and 100% capacity control settings.

C. Cooling Tower Performance Tests:

1. Observe condenser water flow to each cell to observe equal distribution of water. Observe even flow and wetting of fill material.

2. Under peak level conditions, measure condenser water temperature in relation to outdoor wet bulb temperature. Approach should be 7ø or less.

3. With high speed fan operation, observe carryover and wetting/distribution of water over fill.

4. Record amperage draw for each fan motor on high and low speed. Verify correctly sized and installed thermal overload heaters in each starter.

5. Observe control function of cooling tower fans when switching from high to low speed for adequate (90-seconds) time delay to activation of low speed starter.

3.4 EQUIPMENT SAFETY DEVICE CHECKS

A. Submit for approval safety device check procedures in accord with manufacturers' recommended start-up instructions.

B. Chillers shall be interlocked with pumps and flow switches for external safety interlocks. External safeties shall include interlocks through starter auxiliary contacts and flow and/or differential pressure switches wired in series. Pump and/or flow failure must deactivate chiller run circuits.

C. Chillers shall have internal safeties, including low oil pressure, high head pressure, etc. Test each internal safety for machine shutdown capability, based on actual or simulated failures.

3.5 ACCEPTANCE CRITERIA

A. The primary purpose of this section is to witness and verify all of the sequence of operations of the PROCESS CHILLED WATER COOLING SYSTEM CONTROL DIAGRAM shown on sheet M9.6 and additionally called for in the specification section 15715 of the contract documents.

B. Each function and test shall be performed under conditions which simulate as close to an actual operating condition as possible. To that end the contractor shall provide all necessary materials and temporary system modifications to simulate flows, pressures and temperatures necessary to false load the system being tested in order to prove and verify proper operation. Reliance on simulated signals from the DDC system or other indirect indicators is not acceptable. At satisfactory completion of all verified tests, the building system being tested shall be returned to the condition required by the contract documents as a complete and operational system.

C. Demonstrate to the Owner's Representative successful execution of the following FPT's (functional performance tests) in accordance with approved FPT procedures as described in Test Procedures in this Section:

1. Chiller Status and Failure:

    a. System/Equipment to be Tested: Chillers, Chiller control panels, other associated HVAC controls.
        1. CH-1
        2. CH-2
        3. CH-3

    b. Function to be Tested: HVAC controls response to chiller trouble signal from chiller control panel.
        1. Upon shut down of a chiller due to internal controls, verify that trouble status is indicated by initiation of alarm by HVAC controls.
        2. Upon shutdown of a chiller verify that HVAC controls start the next chiller in sequence.

    c. Conditions of Test: Interrupt operation of lead chiller. Test each chiller as if it were the lead chiller.

    d. Acceptable Results: Next scheduled chiller starts automatically and startup moves on through the remaining chillers automatically.

2. Chiller start command and sequencing response:

    a. System/Equipment to be Tested: Chillers, chiller control panels, primary / secondary chilled water pumps, condenser water pumps, and associated HVAC controls.
        1. Chiller CH-1 shall be interlocked with primary chilled water pump CHWP-1 and condenser water pump CP-1.
        2. Chiller CH-2 shall be interlocked with primary chilled water pump CHWP-2 and condenser water pump CP-2.

3. Chiller CH-3 shall be interlocked with primary chilled water pump CHWP-3 and condenser water pump CP-3.

b. Function to be Tested: Response of system components to a start command from the HVAC system.

c. Conditions of Test: Upon a start command from the HVAC control system, verify that the following events occur in sequence:

1. Chiller control sequence is initiated by the DDC system; each chiller is controlled by its own internal control package which adjusts capacity and maintains the discharge water temperature.
2. Verify the following incremental chiller stages:
   a. Stage 1: Chiller CH-1 on
   b. Stage 2: Chiller CH-2 on
   c. Stage 3: Chiller CH-1 & CH-2 on
   d. Stage 4: Chiller CH-1 off, CH-2 & CH-3 on
   e. Stage 5: Chiller CH-1, CH-2, & CH-3 on
3. Verify associated chilled water pumps and condenser water pumps are interlocked.
4. Chiller and associated pumps start. Demonstrate a 15 minute time lag between stages.
5. Demonstrate when chilled water temperature (sensor TS-79) is not maintained at 40° F., (chilled water temperature increasing), the next stage of chiller capacity is initiated. Demonstrate this condition for each stage of loading, for all chillers, from the first stage of cooling (chiller CH-1 in a minimally loaded condition, to the final stage, CH-1, CH-2, & CH-3 all running and fully loaded).
6. Demonstrate when chilled water load decreases, the next lower stage system capacity is initiated. Operate for the following criteria:
   a. When the temperature difference between process load and return decreases to 5° F. (TS-80 minus TS-79), the next smaller chiller stage is initiated, (except to the lowest stage which is minimal).
   b. Verify the following schedule of decreasing stages and capacities:
      1. Stage 2 to stage 1 at 120 gpm
      2. Stage 3 to stage 2 at 250 gpm
      3. Stage 4 to stage 3 at 370 gpm
      4. Stage 5 to stage 4 at 500 gpm
   c. Demonstrate a 15 minute time lag between stages.
7. Verify the following alarm conditions:
   a. For chilled system:
      1. Alarm is initiated when chilled water temperature rises to 42° F.
      2. Alarm is initiated when chilled water temperature drops to 39° F.
   b. For individual chillers:
      1. Alarm is initiated when chilled water temperature rises to 42° F.
      2. Alarm is initiated when chilled water temperature drops to 39° F.

    3. The chiller in alarm shall cycle off.
    4. The next staged chiller shall cycle on.
  - c. Acceptable Results:
    1. Chillers start and stop automatically.
    2. Chillers stage up and down automatically based on system demand.
    3. Each chiller and its respective pumps are interlocked and operate together.
    4. Lag times between starting and stopping of individual chillers and their respective pumps are established.
    5. Alarm conditions a verified for chilled water system and each chiller.

3. Pump Control Sequence:

  - a. System/Equipment to be Tested:
    1. Primary Chilled water pumps:
      - a. CHWP-1
      - b. CHWP-2
      - c. CHWP-3
    2. Secondary Chilled water pumps:
      - a. CHWP-5
      - b. CHWP-6
    3. Water Pumps:
      - a. CP-1
      - b. CP-2
      - c. CP-3
    4. Variable speed drives (VFD's) for the following pumps:
      - a. CHWP-5
      - b. CHWP-6
      - c. CP-1
      - d. CP-2
      - e. CP-3
  - b. Function to be Tested: Response of pump operation from HVAC control system.
  - c. Conditions of Test: Upon a command from the HVAC control system, verify the following events occur in sequence:
    1. Verify pump interlocks are established between respective chillers, chilled water pumps and condenser water pumps.
    2. For each chiller, CH-1, CH-2, & CH-3, verify that chiller will not start until flow has been proven by differential pressure switch associated with each chiller and its respective chilled water pump.
    3. Verify for each chiller and pump combination that if a no flow condition is sensed when chiller is suppose to be on, the following will occur:
      - a. An alarm condition is printed out at the printer.

    b. Upon a chiller cycling off, its respective pumps shall remain on for 5 minutes.
    c. Verify all pump motors will immediately restart after a power interruption is restored.
  4. Verify secondary pumps perform as follows:
    a. Pump CHWP-5 operates as the lead pump.
    b. Pump CHWP-5 alternates with CHWP-6 as manually selected by the Building Operator through the DDC system.
    c. The lead pump is operating continuously.
    d. The lag pump is off, (Standby).
    e. The lead pump is stopped by the DDC system when a no flow condition is sensed by the pump's respective differential pressure transducer and start the lag pump.
    f. An alarm signal has been received by the DDC system indicating failure of the lead pump.
    g. Variable speed drive for failed pump goes to zero speed output signal.
    h. Each pump's respective variable speed drive modulates the pump motor to maintain a differential pressure of 15 psig.
  5. Emergency Power: Pumps designated to run on emergency power shall be tested and verified that they maintain same control and operating functions as if they were on normal power.

d. Acceptable Results:
  1. Respective primary pumps and their chillers are interlocked.
  2. Chillers will not start until respective flows have been proven.
  3. Alarm is received by the DDC system for each primary pump / chiller combination if a no flow condition exists when pump is supposed to be on.
  4. Each chiller's respective primary pump remains on for 5 minutes after chiller is disabled.
  5. All pump motors start as programmed by the DDC system after a power interruption is restored. Maximum restart shall not exceed 6 minutes.
  6. CHWP-5 is on and operates as the lead pump, CHWP-6 is off, (secondary pump system).
  7. The lead secondary pump stops when a no flow conditions is sensed. An alarm signal is received by the DDC system indicating failure of the lead pump.
  8. Each secondary pump is modulated to maintain a differential pressure of 15 psig.
  9. All systems required to function on emergency power operate properly.

4. Condenser Water Control:
   a. System/Equipment to be Tested:
      1. Cooling Towers:
         a. CT-1
         b. CT-2
      2. Condenser Water Pumps:
         a. CP-1
         b. CP-2
         c. CP-3
         d. CP-5
         e. CP-6
      3. Heat Exchangers:
         a. HX-1
         b. HX-2
         c. HX-3
      4. Multiple control valves and temperature sensors, see CHILLED WATER PIPING DIAGRAM, sheet M7.2a and PROCESS CHILLED WATER COOLING SYSTEM CONTROL DIAGRAM, sheet M9.6.
      5. Chemical Feeders.
      6. Heat Trace.
   b. Function to be Tested: Condenser water system and its response in support of the Chilled Water System.
   c. Conditions of Test:
      1. Cooling Towers: Verify the following sequence:
         a. CT-1 operates as the lead tower.
         b. Cooling Towers CT-1 & CT-2 Modulate as follows:
            1. Condenser water supply temperature rises to 85° F., CT-1 cycles on.
            2. If after 15 minutes condenser water temperature has not dropped to 86° F., CT-1 fan #1 cycles on to low speed.
            3. If after 15 minutes condenser water temperature has not dropped to 86° F., CT-1 fan #1 cycles on to high speed.
            4. If after 15 minutes condenser water temperature has not dropped to 86° F., CT-2 cycles on and CT-1 #2 fan to low speed.
            5. If after 15 minutes condenser water temperature has not dropped to 86° F., both fans shall cycle to high speed.
            6. When the entering condenser water temperature drops below 83° F., the reverse sequence shall occur. Verify a 15 minute lag between each stage.
         c. Repeat the above six test with CT-2 operating as the lead tower.

d. Simulate the following tests independently:
  1. A temperature rise to 88° F. and a temperature drop to 80° F. in:
    a. CT-1
    b. CT-2
    c. Supply Manifold (TS-86 & TS-87).
  2. Observe an alarm condition printed out at the printer for each case.

2. Winter Mode Operation: Verify the following sequence:
  a. Changing to winter mode operation requires a manual input to the DDC system by the Owner.
  b. Control valves operate as follows: See diagram 20, sheet M9.6 and diagram 23, sheet M9.7.
    1. CV-74 closes
    2. CV-73 opens
  c. Cooling Towers modulate to maintain condenser water temperature of 85° F. Verify load to towers from 85° F to 95° F in 2° F increments.
  d. Cooling Tower sump heaters cycle on to maintain a minimum 40° F.
  e Cooling Towers shall be capable of being deactivated as follows:
    1. CV-77 shall open.
    2. CV-75 & CV-76 shall close.
  f. Verify the following alarm sequences occur and alarm condition prints out at printer:
    1. Condenser water temperature drops to 75° F, TS-87.
    2. Either Cooling Tower sump drops below 38° F.

3. Summer Mode Operation: Verify the following:
  a. Cooling Towers operate in series with Heat Exchanger, HX-1.
  b. Simulate a requirement for condenser water heat to be reclaimed by the building heating water loop and verify the following:
    1. CV-72 closes.
    2. CV-71 opens.
  c. Observe condenser water temperature at TS-86 maintains 85° F. as condenser water load is varied between minimum chiller load (CH-1 modulated to minimum condition) and maximum chiller load, (CH-1, CH-2, & CH-3 operating at maximum load).
  d. Monitor and record temperature leaving HX-1 as condenser water heat load is varied.
  e. Return system to winter operation an verify proper operation of control valves.
  f. Acceptable Results: Cooling towers respond to all of the varying loads and conditions of the above tests to maintain a return condenser water temperature to the chillers of 85° F (± 2° F). When operating conditions vary beyond system limits alarm conditions exist and the control system is

electronically notified. Control system either automatically adjusts or shuts down the appropriate equipment. Proper control valve operation.

5. Heat Tape:

a. System/Equipment to be Tested: Heat tape freeze protection.
b. Function to be Tested: Heat tape response to a freeze condition.
c. Conditions of Test:
   1. Verify installation of heat tape on the following systems:
      a. Cooling tower spray water piping.
      b. Cooling tower makeup water piping.
      c. Cooling tower spray pump casing.
   2. Simulate for two independent locations on each of the three systems a condition which verifies by means of electrical and thermal metering the following:
      a. Maintain a minimum water temperature in the pipe of 40° F. with ambient air conditions of 0° F.
      b. Demonstrate a localized freezing condition on a small portion of each of the three systems and verify that the self regulating feature of the heat trace tape is functioning.
d. Acceptable Results: The heat trace tape self regulates to maintain a minimum 40° F. water temperature in the pipe with ambient air conditions of 0° F.

3.6 TEST PROCEDURES

A. Submit for approval detailed FPT procedures corresponding to the FPT criteria in Acceptance Criteria in this Section. FPT procedures shall be detailed test instructions, written with sufficient step-by-step information to allow a test to be repeated under identical conditions. List the value for all setpoints and inputs, positions of adjustable devices and acceptable results for each condition tested. Provide a unique alpha-numeric identification for each FPT procedure.

B. Submit for approval test procedure check-off sheets. Number each test procedure check-off item with the same number as the corresponding FPT procedure.

C. Demonstrate successful execution of FPT's listed under Acceptance Criteria in this Section. Sign-off each successful test and obtain the sign-off of the Commissioning Agent or other Owner-designated witness.

END OF SECTION

Appendix 4-11

SECTION 17590 - COMMISSIONING ENVIRONMENTAL CONTROL SYSTEMS

GUIDE SPECIFICATION

The following guide specification is intended to be modified and included in the construction contract documents. Items to be modified will be decided by consultation involving the owner's project manager and the A/E. The A/E is expected to modify this and other specifications as necessary to accurately reflect commissioning requirements based upon specific systems, conditions, and requirements of the project.

PART 1 - GENERAL

1.1 DESCRIPTION

A. The purpose of this section is to describe the commissioning process specific to the environmental control and energy management systems and equipment.

1.2 RELATED WORK

A. Reference Sections 01650, 17100 and 17110 for primary commissioning requirements and responsibilities.

B. Reference Section 15995 for contractor requirements in support of the commissioning process. Refer to Division 15 specifications and plans and contractor shop drawings for system configuration and details of required construction.

C. Reference Section 17595 for testing, adjusting and balancing (TAB) requirements. TAB shall be substantially complete before performing FPTs required in this section.

PART 2 - PRODUCTS

2.1 TEST EQUIPMENT

A. The Contractor shall provide all necessary test equipment.

PART 3 - EXECUTION

3.1 CONSTRUCTION OBSERVATION

A. Obtain and review design documents for overall design intent and the overall required systems configurations.

B. Obtain and review shop drawings and submittals for installation criteria and the required construction details, as they support and further define the systems features.

C. The Test Engineer shall make general inspections at the job site and shall review the following for configuration, quality of construction, adherence to design requirements, and conformance with shop drawings and submittal information.

D. Review Owner specific data:

1. Set points
2. Alarm points
3. Sequence of operation

E. Prepare list of concerns for resolution or special investigation during commissioning process (i.e. pressure and temperature locations, valve piping, damper performance, etc).

F. Check quantity types and locations of hardware:

1. Sensors
2. Pressure and temperature taps
3. Field device panels
4. Direct digital control (DDC) panels
5. Dedicated DDC controllers
6. Controlled devices

G. Check quality of installation:

1. Hardware mounting
2. Cabling and/or tubing routing
3. Terminations
4. Conformance with vendor shop drawings
5. Accessibility after lights and ceiling grid are installed, consistent with OSHA and WISHA regulations concerning fall restraint.

3.2 CLEANING

A. None

3.3 TESTS

A. A test plan shall be developed individually for each subsystem which will define the tests required to ensure that the system, functions, and programs meet technical, operational, and performance requirements. The test plan shall define the schedule for the test exercises, including initial tests, calibration tests, testing of control sequence, and simulation programs. The test plan shall identify the equipment and facilities required for the test.

B. Prior to substantial completion of the environmental control system, the system shall undergo a series of tests to verify its operation and compliance with this specification. These tests shall occur after the Contractor has completed the installation, started up the system, performed their own complete series of tests and debugged the system.

C. The tests described in this section are to be performed in addition to the tests that the Contractor performs as a necessary part of the installation, start-up, and debugging process. As a minimum, the Contractor shall perform their own set of tests prior to those required herein so as to assure the Test Engineer, A/E and Commissioning Agent that the system can successfully complete the tests required herein prior to their execution. Failure of the Contractor to perform their own set of tests first may be cause for rescheduling the tests herein and delay of project substantial completion.

D. System Calibration: Upon completion of the installation, the system installer shall start up the system and perform all necessary testing and diagnostics to ensure proper operation. Submit to the Test Engineer documentation on the calibration of all equipment, including each sensor or control device. Documentation shall include:

1. Step-by-step check-off list of the calibration of each sensor, monitoring/control device and each piece of controlled equipment.

2. Calibration records describing the actual calibration procedures and all test equipment used. Calibration test equipment shall have an accuracy at least equal to the tolerance of the device being adjusted. Test equipment shall provide stabilized field measurements in no more than 30 seconds per reading, utilizing a digital readout display where commercially available.

3. The results of all inspections and tests: Documentation shall be accompanied by letter from the Contractor to the Commissioning Agent stating that calibration of the system is complete.

E. System Test:

1. The system test shall be performed after total system calibration and shall consist of an operational test of each system in the presence of the Commissioning Agent or Owner's Representative. The systems will be tested with points selected at random by the Test Engineer. The executive routine and each application program will be tested, the

performance of the Control Sequences shall be demonstrated, and transmission link accuracy, sensor accuracy and control operation will be reviewed.

2. Systems will not be accepted on a point-by-point or subsystem basis, but only as a whole complete operating system. All executive routine and software functions shall be fully functional. Test a statistically significant sample of all sensors. The size of the sample shall be determined to achieve a confidence level in the validity of the sample of 95%. The Commissioning Agent will select at random the points to be tested.

F. The Test Engineer and Commissioning Agent shall review all of the software for proper point-to-point operation. Upon review of software, a point-to-point test of the environmental control system installation shall commence point-to-point verification. The Contractor shall provide two people equipped with two-way communication and shall test actual field operation of each control and sensing point. The purpose is to test the calibration, response, and action of every point. Any test equipment required to provide the proper operation of the environmental control system shall be provided by and operated by the Contractor. The Test Engineer will be present to oversee, observe, and review the test.

1. Point-to-point Verification (all points, input and output):

   a. Device and Continuity Check:
      1. Sensor to controller check or sensor to operators' control station check as applies.
      2. Command to output
      3. Control/monitored device response check
      4. Virtual points and loop control points are not tested as part of the point-to-point testing.

2. Calibration Check (all sensors). Calibrate sensors at both extremes of operating conditions and at midpoints.

   a. Temperature (sensors)
      1. Immersion:
         a. Ice bath
         b. Boiling water (altitude)
      2. Room:
         a. Side-by-side
         b. Independent thermometer check
      3. Duct:
         a. Side-by-side
         b. Independent thermometer check
   b. Pressure Sensor (Calibrated per NEBB Standards):
      1. Water

        2. Air
        3. Differential pressure
        4. Level
    c. Humidity (Calibrated per NEBB Standards):
        1. Room
        2. Duct
        3. Outside air (OSA)
            a. Sling psychrometer
            b. Hand-held digital humidity meter (thin film polymer sensor
    d. Flow:
        1. Ultrasonic flow meter
        2. Differential pressure on Venturi/orifice

G. When the point-to-point test is successfully completed, perform a series of hard/ware software systems tests shall be performed. The Contractor shall provide two people equipped with two-way communication for these tests. All groups of points that yield a system of control shall be tested for compliance with the sequences of operation. Included in the test, but not limited to, shall be:

1. DC Loop response: The Contractor shall supply a trend data output in graphical form showing the step response of each DDC loop. The test shall show the loop's response to a change in set point which represents a change in the actuator position of at least 25 percent of its full range. The sample rate of the trend shall be from one to three minutes depending on the speed of the loop. The trend data shall show for each sample the set point, actuator position, and controlled variable values. Any loop that yields unreasonably under or over-damped control shall require further tuning by the Contractor. Resubmit trend data following all loop tuning.

2. Interlocks and other sequences for each interlock.

3. Environmental control system control under HVAC equipment failure.

4. HVAC operation under environmental control system equipment failure, including stand-alone operations during communications systems failure.

5. Battery backup.

6. Environmental control system control under power failure/restart.

7. Demand limiting: The Contractor shall supply a trend data output showing the action of the demand limiting algorithm. The data shall document the action on a minute-by-minute

basis over at least a one-half hour period. Included in the trend shall be the building kw, demand limiting set point, and the status of all sheddable equipment outputs.

8. Each reset schedules.

9. Each environmental control system alarm reporting capability.

10. Optimum start/stop: The Contractor shall supply a trend data output showing the capability of the algorithm. The hour-by-hour trend shall include the output status of all optimally started and stopped equipment, and the temperature sensor inputs of all affected areas.

11. Environmental control system control during a fire alarm.

12. The Test Engineer will be present to oversee, observe, and review the tests.

H. The Division 15 Contractor will supply the Test Engineer with two (2) debugged printouts of all environmental control system software. Also supply all user's programming and engineering manuals required to interpret the software. Included in the printouts, though not limited to, shall be the following:

1. Point database.

2. All custom control program written in the environmental control system control language.

3. All parameters required for proper operation of environmental control system control and utility firmware such as start/stop routines, etc.

4. Printouts or plotted copies of the interactive system graphics.

I. The software printout shall be fully documented for ease of interpretation by the Test Engineer and Owner, without assistance from the Section 15900 Contractor. English language descriptions shall be either integrated with or attached to the environmental control system printout. The intent of supplying the above software printouts is to determine compliance with specification requirements. Specifically, the following shall be documented:

1. All point (I/O and virtual) names.

2. All environmental control system programming language commands, functions, syntax, operators, and reserved variables.

3. Use of all environmental control system firmware.

4. The intended actions, decisions, and calculations of each line or logical group of lines in the custom control program(s). Sequences of operation are not acceptable for use in this documentation requirement.

5. Complete descriptions of and theories explaining all software and firmware algorithms. The algorithms to be described include, but are not limited to, PID, optimum start/stop, demand limiting, and chiller and heat exchanger optimization.

6. Provide a table of contents to the documentation which locates the sections of the documentation and describes which programs or program sections are for each piece of controlled/monitored equipment.

7. Provide flow charts using IEEE symbol nomenclature that demonstrates the software's algorithms and flow logic.

J. The environmental control system will not be accepted as meeting the requirements of substantial completion until all tests described in this section have been performed to the satisfaction of both the Test Engineer and Commission Agent. Any tests that cannot be performed due to circumstances beyond the control of the Contractor shall be exempt from the substantial completion requirements if stated a such in writing by the Commissioning Agent and Test Engineer. Such tests shall be performed as part of the environmental control system warranty.

K. Pneumatic Piping: Entire pneumatic piping system shall be tested by placing it under 30 pounds pressure for 24 hours, except piping serving fan pitch controllers, which shall be tested at 125 pounds pressure. Pressure drop during test shall not exceed five percent.

3.4 EQUIPMENT SAFETY DEVICE CHECKS

A. Refer to sections 17110, 17120, 18130, 18140, 17150, paragraph 3.4 each section, for specific safety device checks.

3.5 ACCEPTANCE CRITERIA

A. The primary purpose of this section is to witness and verify all of the operations of the Environmental Control Systems shown on the drawings and called for in the specifications of the contract documents.

B. Each function and test shall be performed under conditions which simulate as close to an actual operating condition as possible. To that end the contractor shall provide all necessary materials and temporary system modifications to simulate flows, pressures and temperatures necessary to false load the system being tested in order to prove and verify proper operation. Reliance on simulated signals from the DDC system or other indirect indicators is not acceptable. Other than limited use of virtual points to include outside air temperature, fan discharge temperature and other sensed points whose functionality to the overall system has been established by other independent test. At satisfactory completion of all verified tests, the building system being tested shall be returned to the condition required by the contract documents as a complete and operational system.

C. Demonstrate to the Owner's Representative successful execution of the following FPT's (functional performance tests) in accordance with approved FPT procedures as described in Test Procedures in this Section:

1. Environmental Control Systems:

   a. Systems / Equipment to be Tested: Mechanical and Electrical environmental control systems.
   b. Functions to be Tested: It is recognized that many of the control functions required of the Mechanical and Electrical systems will be tested and verified in other sections of Division 17. It is not the intent of this Section to duplicate previously tested, verified and approved control functions. It is the intent of this section however, to complete the process of testing and verifying all of the environmental control system functions not done by other sections of Division 17, and to test the building control functions as they relate and interact with each other.
   c. Conditions of Test:
      1. Operate all of the buildings' environmental control system functions as called for by the contract drawings and specification, Division 15 and Division 16, both individually and interactively.
      2. Create the following electrical conditions:
         a. Normal power on to building.
         b. Normal power off, emergency power on to building.
         c. Normal power restored to building.
   d. Acceptable Results: All environmental control functions operate successfully, (individually and interactively), as described by the contract documents.

3.6 TEST PROCEDURES

A. Submit for approval detailed FPT procedures corresponding to the FPT criteria in Acceptance Criteria in this Section. FPT procedures shall be detailed test instructions, written with sufficient step-by-step information to allow a test to be repeated under identical conditions. List the value for all setpoints and inputs, positions of adjustable devices and acceptable results for each condition tested. Provide a unique alpha-numeric identification for each FPT procedure.

B. Submit for approval test procedure check-off sheets. Number each test procedure check-off item with the same number as the corresponding FPT procedure.

C. Demonstrate successful execution of FPT's listed under Acceptance Criteria in this Section. Sign-off each successful test and obtain the sign-off of the Commissioning Agent or other Owner-designated witness.

3.7 TRAINING

A. Coordinate the initial training of maintenance and management personnel. Instruction shall be provided in adjustment, operation and maintenance, including pertinent safety requirements of the equipment and systems specified. Orient the training specifically to the systems installed rather than a general (canned) training course. Instructors shall be thoroughly familiar with all aspects of the subject matter they are to teach.

B. Coordinate training necessary to ensure competence in the operation of each system by the operating personnel. Provide instructors, literature, and necessary equipment to train the personnel. Training shall be completed prior to the system test.

C. Coordinate a training program 30 days prior to the training sessions. Training shall include the following:

1. General system architecture
2. Operation of computers and peripherals
3. System function and operation
4. System design as installed
5. System initialization procedure
6. Operator commands
7. Failure-recovery procedures
8. Report formats
9. Alarm formats
10. Temperature control sequences
11. System programming
12. Program editing

D. Operator Training: For each subsystem, coordinate classroom instruction and "hands-on" operational instruction. The hands-on instruction shall be a structured training session. Training shall be provided at a location provided by the Owner.

E. Supervisory Training: Classroom instruction and "hands-on" instruction shall be coordinated. The training shall emphasize the general system concepts, reporting, and customized programming of the system.

F. Review Training Manuals: The training manuals shall be structured to provide an overview of system operation. Material shall correspond to the information covered in the training program. Typical section would include the following:

1. General system architecture
2. Operation of computers and peripherals
3. System function and operation
4. System design as installed
5. System initialization procedure
6. Operator commands
7. Failure-recovery procedures
8. Report formats
9. Alarm formats
10. Temperature control sequences
11. System programming
12. Program editing
13. Documents shall be structured to enable training on a self-study basis. The documentation shall be written in concise terms and in language which is within the grasp of mechanical/electrical technicians who are not experts in digital electronics. Provide documents in binders per requirements of Division 1.

G. System Operations Manual: The systems operations manual shall identify the operation requirements for each system and document, the system design and the specific functions of the equipment. This manual shall expand the information as presented in the training manual. Operator machine interactions and all instructions shall be functionally described as required for system operation. The manual shall provide complete operating instructions for each system and shall include, but not be limited to, the following:

1. Computer executive routine and disk operating system manuals
2. Computer and peripheral reference manuals
3. Troubleshooting documentation
4. Field interface device reference and programming manual
5. Alarm assignment
6. Failure-recovery procedures
7. Reports/alarm message/display formats
8. I/O summaries, including point number assignments, control and monitoring functions, and software subscriptions
9. System software subscription organized by software routine

10. Field panel terminal assignments.
11. The documentation shall include procedures for:
    a. Revising setpoints
    b. Adding new direct digital control logic and control loops
    c. Editing and revising the program and data files

H. Software and Program Documentation: Supply documentation describing all computer programs. Simplified block diagrams and written descriptions shall be furnished to facilitate easy understanding of program operation. Provide description of all data and program files (data format, record format, and field size). Provide programming procedures for each program.

I. Control System Documentation:

1. Control system documentation shall describe all control systems and shall describe all control systems necessary to satisfy control requirements and sequences. Control diagrams, system diagrams, system interface diagrams, and flow diagrams shall be provided.

2. Provide one set of diagrams mounted, framed, and under glass adjacent to each control system.

3. All control valves, dampers and actuators, electronic and pneumatic controls, motor starters, electric hand-off auto switches, sensors, monitoring devices, manual reset switches, and devices provided for operator control shall be documented, described, and locations identified.

3.8 DOCUMENTATION

A. For each subsystem, supply all training manuals, operation manuals, software and program documentation, control documentation, instrumentation documentation, and maintenance manuals as described herein. These manuals shall document all operations and maintenance procedures in a clear, concise, step-by-step fashion and shall be assembled under separate covers.

B. In preparing data required by this Section, use only personnel who are thoroughly trained and experienced in operations and maintenance of the described items, completely familiar with the requirements of this Section, and skilled in technical writing to the extent needed for communicating the essential data.

C. Record Drawings:

1. Ensure that a complete set of redline prints of contract drawings is provided and shop drawings for record mark-up purposes throughout the contract time are maintained on the job site. Corrections and changes made during the progress of the work shall be recorded continuously by the Contractor on a set of prints kept readily available at the project during construction. Give special attention to work which will be concealed and difficult to measure and record at a later date, particular items which may require servicing or replacement during the life of the project, such as vales, traps, dampers, etc.

2. Ensure that all record drawings shall be generated by computer-aided drafting using AutoCAD Version 12.0 or later.

END OF SECTION

Appendix 4-12

SECTION 17595 - COMMISSIONING, TESTING, ADJUSTING AND BALANCING

GUIDE SPECIFICATION

The following guide specification is intended to be modified and included in the construction contract documents. Items to be modified will be decided by consultation involving the owner's project manager and the A/E. The A/E is expected to modify this and other specifications as necessary to accurately reflect commissioning requirements based upon specific systems, conditions, and requirements of the project.

PART 1 - GENERAL

1.1 SCOPE

A. Section Includes: The purpose of this section is two fold: first to describe the requirements of the Contractor to provide all necessary services to perform testing, adjusting and balancing (TAB); and secondly to describe the commissioning process specific to testing, adjusting and balancing (TAB) systems and equipment. Systems include, but are not limited to, heating, ventilating, and air conditioning, supply air and exhaust air systems, hot water heating, central cooling water, chilled water, condenser water, special piping, high purity piping, etc.

1.2 CODES, REGULATIONS AND STANDARDS

A. All work shall conform to the following codes, regulations, and standards of latest issue:

1. Associated Air Balance Council (AABC), "National Standards for Field Management and Instrumentation Total System Balance," Volume One, No. 81266.
2. ASHRAE Handbook, 1987 HVAC Systems and Applications, Chapter 57.
3. AMCA Publication 203 Fan Application Manual, Part 3, Field Performance Measurement.
4. National Institute of Health (NIH)
5. Industrial Ventilation Guide, American Conference of Governmental Industrial Hygienist.
6. National Environmental Balancing Bureau (NEBB), "Procedural Standards for Testing, Adjusting, Balancing of Environmental Systems".

1.3 RELATED WORK

A. Reference Sections 01650, 17100 and 17110 for primary commissioning requirements and responsibilities.

B. Reference Section 15995 for contractor requirements in support of the commissioning process. Refer to Division 15 specifications and plans and contractor shop drawings for system configuration and details of required construction.

C. During the balancing work, list all items which are installed incorrectly or have not been installed in accordance with the contract drawings and/or specifications. This shall include all air distribution, piping, pumping, heating and cooling systems.

D. During the balancing work, advise the Test Engineer of any deficiencies in the construction or systems such as lack of balancing valves, dampers, etc., that adversely impact the "balance-ability" of systems.

E. During the balancing work, report all deficiencies in controls, air valve leakage, damper leakage, mixing box leakage, thermostat malfunction, excessive noise in the HVAC system, etc., that adversely impacts the quality of the HVAC systems.

F. Obtain from the Contractor an unmarked copy of the plans and specifications to be used during the system balance. These drawings are to be maintained on the job site with notes and red-lines indicating as-built conditions discovered in the course of the TAB work.

G. Records and test data shall be kept throughout the course of the project that pertain not only to test results, but observations relative to quality of construction, completeness of components and systems, and overall integrity of the HVAC systems.

1.4 SYSTEM CHANGES

A. General: Changes or additions of sheaves, belts, blade pitch, volume dampers, and access to system components shall be provided by Section 15810, as required by the testing and balancing agency, at no additional cost to the Owner.

1.5 TESTING AND BALANCING AGENCY

A. Agency Qualifications: The Contractor, as part of this contract, shall obtain the services of a qualified agency to perform the testing and balancing work as herein specified. The Contractor shall submit the name of the proposed agency to the Owner's Representative for review within 60 days after the contract award. The criteria for determining qualifications shall be membership in the AABC, or certification by the NEBB, and the agency shall have not less than 5 years experience on projects of similar scope and complexity. The agency shall be independent of the installing contractors or equipment suppliers for this project.

Submit a current list of projects for which the balancing contractor provided services, including references and phone numbers, and name of principal technician.

B. Qualified Agencies: The Contractor, as part of this contract, shall obtain the services of one of the agencies listed below to perform the testing and balancing work as herein specified. The agency shall be independent of the installing contractors or equipment suppliers for this project.

1. (name to be entered)
2. (name to be entered)
3. (name to be entered)
4. or Owner approved equal

1.6 JOB COORDINATION

A. General: Within 60 days of the start of construction, review the plans, specifications and installation of all the affected systems. Submit a written report to the Owner's Representative indicating any recognized deficiencies in the systems that would preclude the proper adjusting, balancing, and testing of the systems.

1.7 AGENDA

A. General: Submit two copies of an agenda for review by the Engineer at least 30 days prior to the start of testing and balancing. The agenda shall include the following:

1. An outline of tasks to be performed at the job site (in the sequence they are to be performed).
2. An explanation of the equipment to be used for each type of field measurement. Indicate the correction factors to be used for area, velocity, CFM, density, GPM, etc.
3. Indicate equations to be used for data which is to be calculated.
4. Indicate the location of each pitot tube traverse to be performed.
5. An organized compilation of all of the forms that will be used to record data at the job site. Each form shall be filled in with installation and design data as specified and shall include blank spaces for the recorded test data. Indicate all data specified to be recorded. The forms shall be organized in a manner which is satisfactory to the Owner's Representative. The final organizational format of the submitted forms shall be used for the finished testing and balancing report.

1.8 PROCEDURES, GENERAL

A. Requirements: Adjust systems and components thereof to perform as required by drawings and specifications.

B. Initial Testing: Prior to actual start of testing and balancing verify that the systems and equipment are ready for balancing and submit a letter to the Owner's Representative so stating and also describing any deficiencies found. Correct air and water system performance deficiencies disclosed by initial testing prior to balancing the systems.

C. Test Duration: Operating tests of heating and cooling coils, fans and other equipment shall be of not less than 4 hours duration, after stabilized operating conditions have been established. Capacities shall be based on temperatures and air and water quantities measured during such tests.

D. Off-season Testing: In consideration that testing and balancing may be scheduled in the season other than that for which the equipment applies, the agency shall provide load to test the equipment. The heating system shall be tested under whatever sustained load can be provided by combination of ambient and cooling apparatus. If the cooling system is tested in the winter, the heating system shall be used to generate whatever sustained load can be provided. Full operational tests shall be performed during the next available heating and/or cooling season as may be requested by the Owner's Representative and scheduled with the Owner. Utility expenses for these tests will be provided by the Owner.

E. Instrumentation: Method of application of instrumentation shall be in accordance with the approved agenda. Furnish all personnel, instruments, and equipment for tests specified herein.

1. Accuracy of Instruments: Instruments used for measurements shall be accurate to within the requirements of NEBB. Provide calibration histories for each instrument for examination. Calibrate each test instrument by an approved laboratory or by the manufacturer. The Engineer has the right to request instrument recalibration, or the use of other instruments and test methodology, where accuracy of readings is questionable.

2. Application of Instruments: Comply with manufacturer's certified instructions.

F. Filters: Verify that new air filters have been installed after the test run and before the start of testing and balancing.

G. Air Vents: Blow off all manual air vents before the start of testing and balancing.

H. Air Pattern Controllers: Adjust air pattern controllers, grille and register blades for the air diffusion patterns indicated prior to testing and balancing.

I. Wiring and Controls: All wiring and controls shall be completed and tested before the start of testing and balancing. Owner witnessed testing. Installation shall be completed and approved by the Owner's Representative before the start of balancing.

1.9 BALANCING REPORTS

A. Report Submittals

1. First submittal: Two (2) copies of the rough draft report for review by the Test Engineer and Commissioning Agent, to include:
    a. A list of items which will prevent the balancer from providing a full and complete balance.
    b. Narratives that describe all problem areas that may require major construction or design changes.
    c. Narratives that describe the building systems and control systems to demonstrate comprehension of systems operation, including system diversity.
    d. The balancing agenda which reiterates the scope of the balancing work and the intended order of activity.

2. Pre-final submittal: Three (3) copies of the complete report; for approval by the Test Engineer and Commissioning Agent; and information for the A/E.

3. Final submittal: Four (4) copies of the approved report; in binders per requirements indicated in Division 1, General Requirements; except imprint bound edge of volumes with the name of the building and the words "Testing, Adjusting, and Balancing Report". Imprint front of the volume with the name of the building, project name, project number, Owner, General Contractor, Mechanical Subcontractor, Architect, Mechanical Engineer, and the TAB firm; three (3) copies for the Owner and one (1) copy for the A/E.

B. The pre-final and final reports shall include a narrative and the data necessary to describe the system(s), operating equipment, and how they function. Identify equipment using the construction drawing identifiers. Provide ventilation and heating hot water piping riser diagrams if either one is not already a part of the construction drawings. Include data required by: "3.5 Air System Data" and "3.6 Water System Data".

PART 2 - PRODUCTS

2.1 TEST EQUIPMENT

A. Instrumentation shall be provided as necessary and appropriate to perform the work. The type and number of instruments utilized shall be determined by the type of systems involved and the number of personnel required to complete the work by the time stipulated. The instruments shall be recently factory calibrated and shall be used with the factory-determined application factors. This instrumentation shall include, as appropriate, but not be limited to, the following, or approved equal:

B. Airflow/Pressure

1. Capture box
2. Inclined manometer
3. Anemometer; 4 inch Biram type
4. Anemotherm; Anemostat Model 60
5. Velometer; Alnor Type 3002
6. Dwyer "Magnehelic"; 0 to 4 inch wg; 0 to 10 inch wg
7. Pitot tubes; static and velocity; Dwyer Model 400

C. Water Flow/Pressure

1. Barco meter and calibration charts
2. Pressure gauges
3. P&T insert probes

D. Temperature

1. P&T insert probes
2. Duct probes
3. Surface temperature pyrometer; Alnor Type 4200
4. Electronic readout devices
5. Recorders

E. Humidity

1. Sling psychrometer
2. Electronic humidity sensor

F. Electrical

1. Amprobe
2. Voltmeter

2.2 TEST EQUIPMENT

A. The Contractor shall provide all necessary test equipment.

PART 3 - EXECUTION

3.1 CONSTRUCTION OBSERVATION

A. Obtain and review design documents for overall design intent and the overall required systems and configurations.

B. Obtain and review shop drawings and submittals for installation criteria and the required construction details, and their support and further define the systems features.

C. Make periodic inspections of the HVAC systems components, ductwork, and piping systems as constructed; reviewing the following for configuration, quality of construction, adherence to design requirements, and conformance with shop drawings and submittal information.

3.2 GENERAL TESTING, ADJUSTING, AND BALANCING PROCEDURES

A. Records shall be maintained at all times which shall readily indicate all steps, adjustments, and intermediate and final readings. The records shall indicate on each trial whether a damper or balancing device was cut or opened. The records shall be maintained on reproducible type forms which shall include measurement locations, design capacities, appropriate manufacturers' performance factors, and dates and names of personnel involved, and shall be included in the report.

B. Final settings shall be clearly marked on each balancing valve, quadrant, etc.

C. Occasionally work may have to be performed in areas that are partially or fully occupied by the Owner, which may require the work to be accomplished during other than normal working hours. Such occupancy shall not be considered justification for any deviation for the requirements outlined herein or any extra payments. Where overtime work is required for expeditious completion of the balancing work, payment of premium rates for such work shall not be allowed without specific written approval by the Owner's Representative in advance.

D. System operation will be by the Contractor to suit the requirements of the balancing work. System filters shall be new at start of testing, adjustment, and balancing work.

E. Demonstrate agreement of recorded and measured data. Upon completion of final balance settings, notify the Test Engineer and Commissioning Agent. Repeat flow readings at five percent of the outlets as directed by the Commissioning Agent or Owner's Representative. If repeat readings differ by more than five percent from the final values recorded on the balance report forms, balancer shall make corrections to the system balance and this procedure shall then be repeated.

F. Resourcefulness is frequently required in order to properly balance some of the more complex and intricate systems. This may dictate the use of methods and techniques not herein before stated. Where "standard" balancing procedures cannot, due to physical conditions or other circumstances be employed, alternate methods shall be determined and approved by the Test Engineer and Commissioning Agent.

3.3 AIR SYSTEM PROCEDURES

A. General: Prior to air system balancing, verify the following:

1. Systems shall be running in control and modulating with reasonable flows and pressures
2. Clean air filters
3. All fire, smoke and isolation dampers open
4. All ducts intact/no leakage
5. Test and adjust blower rpm to design requirements
6. Test and record motor actual and full load amps
7. Test and record system preliminary static pressure profiles across all fan system components at intermediate points in branch ducts, and at end of runs.

B. Adjustments: Adjust all air handling systems to provide the required design air quantity to, or through, each component as indicated.

C. Balance: Use flow adjusting (volume control) devices to balance air quantities only; i.e. proportion flow between various terminals comprising system, and only to the extent that their adjustments do not create objectionable air motion or sound. Make final measurements of air quantity, after the air terminal has been adjusted to provide the optimum air patterns of diffusion.

D. Fan Adjustment: Total air system quantities shall be varied by adjustment of fan speeds utilizing the VFD's. Terminal control boxes, manual volume dampers, etc. shall not be used for fan adjustment. Fans, air handling equipment, or other equipment with vibration levels considered by the balancer to be excessive shall be brought to the attention of the Test Engineer.

E. Variable Frequency Drives (VFD) or (VSD)/Filter Pressure Drop Simulation Test: The VFD's shall be positioned when the filter bank(s) are at their maximum allowable pressure drop. Simulate filter loading by gradually covering the face of the filters and observing the VFD modulation as the filter pressure drop increases. If the VFD is at its maximum operating condition and with the maximum dirty filter condition and the static pressure setting is sufficient to supply design volumes to all the terminals and the inlet static pressure to VAV boxes is at least .75", then the fan speed shall be decreased. Adjust the static pressure sensor setting to the lowest level that will still obtain the required terminal air volumes and VAV box inlet pressure. After consultation with the Test Engineer and the Owner's Representative, the static pressure sensor shall be moved to a location deemed appropriate by the testing and balancing agency if it is reading incorrectly (due to poor positioning or air turbulence occurring from a known or unknown cause).

F. Air Measurement:

1. General: Total system air quantities shall be determined by summing the air quantities at the terminals served. Total system air quantities shall also be determined by pitot tube traverse and by fan performance data.

2. Pitot Tube Traverse: Perform pitot-tube traverses at each fan, and (in addition), if the fan serves more than one floor, perform traverses on each branch feed to each floor. Pitot tube traverses may be omitted at branch feeds to each floor if all of the branch feeds are individually less than 2,000 CFM.

3. Test Holes: Test holes shall be in a straight duct, as far as possible from elbows, bends, takeoffs, and other turbulence generating devices, to optimize reliability of flow measurements. Plug holes after testing and patch insulation where required. Indicate test hole location with marker.

4. Air Terminal Balancing: Preliminary measurement of flow rates by means of velocity meters applied to individual terminals, with or without cones or other adapters, may be used for balancing. Final measurement of air quantities at each type of air terminal (inlet and outlet) shall be determined only by the method approved in the balancing agenda.

When complete, at least one air path from each air outlet or inlet shall have all volume dampers wide open. This is to ensure minimum static pressure build-up in the system as a result of balancing. Balance air terminals to within plus or minus 5% of the volume flow rate values listed on the drawings. In all rooms or areas where the supply and exhaust (or return) volume flow rates indicated on the drawings differ for the purposes of pressurizing a room or area, the 5% degree of accuracy in balancing the air terminals shall not change the difference between the supply and exhaust (or return) volume flow rates.

G. Economizer Damper Minimum Position Test:

1. General: A test of the outside air minimum damper position shall be performed (using the temperature averaging method) on systems equipped with economizer dampers. This test should be done with the assistance of the control contractor's start-up person (coordinate accordingly). Perform this test when the outside air temperature is at least 15°F higher or lower than the return air temperature. The outside air damper may be at its minimum position under two circumstances. The first is when the outside air temperature is significantly below the mixed air set point. The second is when the outside air temperature is above the economizer cycle high limit temperature (approximately 75°F) or above the return air temperature (see Section 15900, SEQUENCE OF CONTROL).

2. Conditions: A minimum position test may be conducted under either one of these conditions. It may also be conducted under any of the following conditions:

   a. By adjusting the high limit temperature set point below the actual outside air temperature.
   b. By false loading the outside air temperature sensor above the return air temperature.
   c. By false loading the return air temperature sensor below the outside air temperature.

3. Procedure: Once the outside air damper has been induced to its minimum position, perform a temperature traverse in the mixed air plenum or, preferably, downstream (with coils off) to determine an average mixed air temperature. Measure the outside air temperature and return air temperature and calculate the desired mixed air temperature using the equation below at the specified minimum position. Adjust the minimum position controls as necessary to obtain a measured mixed air temperature within ± 0.5°F of the calculated mixed air temperature (if the temperature difference between outside air and return air is 30°F or greater, a margin of ±1°F is acceptable).

   a. $\text{MAT} = \frac{\text{M (OSAT - RAT)}}{100} + \text{RAT}$

   b. Where:

      1. MAT = mixed air temperature (°F)

2. OSAT = outside air temperature (°F)
3. RAT = return air temperature (°F)
4. M = specified minimum % outside air

c. 100% Open Test: OSA between SAT and RAT

H. FVAV and VAV Box Adjustment: CV and VAV terminal control units shall be adjusted for the air quantities indicated. Adjust thermostats which control VAV boxes and record maximum and minimum CFMs. The velocity pressure off of the box flow sensing probe shall be recorded at both the maximum and minimum CFMs.

I. Stair Pressurization Systems: Adjust the relief air automatic control damper to 2,500 CFM. Adjust fan speed as necessary to obtain a stair pressurization (relative to outside atmosphere) of between .15 and .30 inches W.G. Design conditions are for .2" pressure relative to outside atmosphere with all doors closed. Where multiple registers are used to introduce pressurization air to the stairwell, adjust them to equal air quantities. In addition to the requirements of Division 17, a final test witnessed by the Fire Marshal shall be performed to demonstrate that the systems meet the code requirements for performance.

3.4 WATER SYSTEM PROCEDURES

A. Adjustment: Adjust heating, cooling, condensing water, special piping, high purity piping systems to provide required quantity to, or through, each component.

B. Metering: Measure water quantities with pitot-type meters (Anubar), venturi meters, or circuit setters. Measure temperatures and pressures from thermometers, pressure gauges or Pete's plugs. Adjust systems to provide the design pressure drops through the heat transfer equipment (coils, converters, etc., except room units) prior to the capacity testing. Where flow metering fittings are not installed, determine flow balance by measuring temperature differential across the heat transfer equipment. Perform measurement of temperature differential with the air system, adjusted as described herein, in operation.

C. Automatic Controls: Position automatic control valves for full flow through the heat transfer equipment during tests.

D. Pump Differential Pressure Bypass Valves: Verify operation is as specified and indicated. If valve is working improperly, coordinate with the temperature controls installer and adjust for proper operation.

E. Three-way Valves: Pressure drop through bypass circuits at three-way valves shall be adjusted to balance that through the coil circuit.

F. Built-up Coil Banks: Adjust flow through coils for equal flows.

G. Makeup PRVs: Check and adjust makeup water pressure reducing valves as necessary to obtain indicated static pressures.

H. Distribution: Adjust distribution by means of balancing devices (cocks, valves, and fittings) and automatic flow control valves. Do not use service valves for adjustment. Where automatic flow control valves are utilized in lieu of venturi tubes, record pressure drop and flow through the valve.

I. Capacities: Adjusted capacities shall be within a tolerance of plus or minus 5% from the design ratings shown on the contract drawings or, when leaving water temperatures are used to indicate a balanced condition, within a tolerance of plus or minus 1°F. When complete, at least one path from the pump discharge to the pump intake (except for the balancing valve used to set the pump operating head) shall have balancing valves wide open. This is to ensure minimum friction drop in the system as a result of balancing.

J. Special Procedures: When the pump capacity (as designed) is less than total flow requirements of individual heat transfer units of system served, full flow may be simulated by the temporary restriction of flow to portions of the system. In such a case, delineate specific procedures in the agenda.

3.5 CERTIFIED REPORTS

A. Submittal: Submit three copies of the reports described herein, covering system performance and air motion (FPM), to the Engineer prior to final tests and inspection.

B. Instrument Records: Include types, serial numbers, and dates of calibration of all instruments.

C. Reports: Reports shall identify conspicuously items not conforming to contract requirements.

D. Recorded Values: All quantities recorded in report shall be measured unless report notes it as a calculated value. Calculate values only where measuring is not possible.

E. Air Terminal Numbering Sketch: In lieu of an agency air terminal numbering sketch, obtain three sets of half-size prints for inclusion into the certified report. The agency shall color code the different duct systems, number the air terminals (in red) to correspond to the numbers in the report, and indicate test holes and miscellaneous measurement locations.

3.6 AIR SYSTEM DATA

A. Report: The certified report shall include for each air handling system the data listed below.

B. Equipment (fan or factory fabricated air handling unit):

1. Installation Data:

   a. Equipment schedule identification
   b. Manufacturer and model number
   c. All nameplate data
   d. Type/size
   e. Arrangement, discharge, and class
   f. Motor HP, voltage, phase, cycles, and full load amps
   g. Location in the building
   h. Motor and fan sheave size, manufacturer and model number
   i. Number of belts, belt size, manufacturer and model number

2. Design Data:

   a. Data listed in schedules on drawings and in the specifications.

3. Fan Recorded (Test) Data:

   a. Date and time of readings and name of technician
   b. CFM, measured by traverse at or near the fan
   c. Static pressure readings across each component in the fan casing or plenum (each coil, filter bank, control damper, louver, etc.)
   d. Total pressure readings, where appropriate
   e. RPM
   f. Motor operating amps and volts (for each leg)
   g. Motor operating BHP
   h. Fan curve with operating point
   i. Fuse and starter heater sizes
   j. Damper positions (outside air, return air, etc.)
   k. Signify that sheave alignment and belt tension have been checked and adjusted
   l. VFD operation test observations and static pressure sensor set point
   m. Economizer damper minimum position test observations and data

4. Pitot Tube Traverse:

   a. Duct size(s)
   b. Number, location and cross-section sketch of each pitot-tube (pressure) measurement. Perform pitot tube traverses for all air handling systems whose supply air, exhaust air,

return air, or outside air ductwork (risers and take-offs) have a cross sectional area of 400 square inches or larger.

- c. Sum of velocity measurement, excluding pressure measurements
- d. Average velocity
- e. Recorded (test) CFM
- f. Design CFM

5. Individual Air Terminals:

   - a. Terminal identification (supply or exhaust, location and number designation)
   - b. Type, size, manufacturer and catalog identification
   - c. Design and recorded quantities - CFM at minimum and maximum settings
   - d. Design and measured air flow of primary and recirculated air.
   - e. Deflector vane or diffusion cone settings
   - f. Applicable factor for application, velocity, area, etc.
   - g. Design and recorded velocities - FPM (state "core," "inlet," etc., as applicable)

6. Heat Pumps and VAV Boxes:

   - a. Manufacturer and model number
   - b. Location and number
   - c. Inlet size and number coil rows
   - d. Design maximum CFM
   - e. Design minimum CFM (only for VAV boxes)
   - f. Measured maximum CFM and box velocity pressure reading
   - g. Measured minimum CFM and box velocity pressure reading (only for VAV boxes)
   - h. Check for easily-opened heating coil access door

7. Electric Heating Coils:

   - a. Fuse size and continuity test on each fuse
   - b. Coil KW, voltage, operating amps
   - c. Acknowledge that continuity test across fuse indicates current flow through fuse.
   - d. Acknowledge that thermostat activates each step of heat.
   - e. Acknowledge that continuity test across air flow or air pressure switch indicates an operable switch throughout the range of airflow of the coil.
   - f. Acknowledge that reset is operable.
   - g. Report any indications of localized overheating on coil (i.e. red versus black elements, high limit cycling coil, etc.)

8. Stair Pressurization Data:

   a. Record all data required for code compliance and record all air terminal volumes.

9. Fume Hoods:

   a. Installation Data:

      1. Identification (room or suite numbers, name, location, number designation, exhaust fan)
      2. Manufacturer's name, model or size, and type (i.e. fume, perchloric, walk-in, canopy, bio-safety)
      3. Inlet face area of hood with sash at maximum height (with sash stop released), unless otherwise indicated.
      4. Design is inlet flow at 100 fpm through open inlet face area
      5. Final setting shall conform with UW EH&S measurements using NIH standards
      6. Flow readings (at high and low speeds for two-speed hoods) from an inlet area traverse using a 1'-0" by 1'-0" grid

   b. Design Data:

      1. Maximum sash height
      2. Opening width
      3. Opening area
      4. Face velocity
      5. Total CFM

   c. Test Data:

      1. Maximum sash height
      2. Opening width
      3. Opening area
      4. Face velocity
      5. Total CFM
      6. Special air valve static pressure setting

3.7 WATER SYSTEM DATA

A. Report: The certified report shall include for each water conveying system the data listed below.

1. Pumps:

   a. Installation Data:

      1. Equipment schedule identification
      2. Manufacturer and model
      3. All nameplate data
      4. Size
      5. Type drive
      6. Motor HP, voltage, phase, and full load amps
      7. Location in the building

   b. Design Data:

      1. Static pressure (at no-flow) at the makeup water connection
      2. GPM
      3. Head
      4. RPM
      5. BHP and amps

   c. Recorded Data:

      1. Date and time of reading
      2. Static pressure (at no-flow) at the makeup water connection
      3. Discharge pressures (full-flow and no-flow)
      4. Suction pressures (full-flow and no-flow)
      5. Operating head (full-flow and no-flow)
      6. Operating GPM (from pump curves if metering is not provided)
      7. Pump curve with operating point(s)
      8. Operating amps and volts (for each leg)
      9. Full-flow amps
      10. No-flow amps
      11. Calculated BHP
      12. Indicate pump differential pressure bypass valve test results
      13. Pressure at highest point in system

2. Converters and Heat Exchangers:

   a. Installation and Design Data:

      1. Equipment schedule identification
      2. Manufacturer, model, type, and size

    3. GPM
    4. Inlet (entering) and outlet (leaving) temperatures
    5. Steam inlet pressure
    6. Water pressure drop
    7. Location in building

  b. Recorded Data:

    1. Date and time of readings
    2. GPM
    3. System side entering and leaving water temperature
    4. Water pressure drop
    5. Heating (or cooling) media - steam pressure and temperature and condensate temperature, or entering and leaving water temperature
    6. Heating (or cooling) media - flow (GPM or lbs. per hour)
    7. Heating (or cooling) capacity

3. Air Heating and Cooling Coils:

  a. Installation and Design Data (Each Coil):

    1. Load in BTU per hour
    2. GPM
    3. Entering and leaving water temperature
    4. Entering and leaving air conditions (D.B. and W.B.)
    5. CFM
    6. Water pressure drop
    7. Air pressure drop
    8. Number of coils
    9. Finned length
    10. Finned height
    11. Face area
    12. Face velocity
    13. Number of rows
    14. Fins per inch
    15. Manufacturer and model

  b. Recorded Data:

    1. Date and time of readings
    2. Type of equipment and identification (location or number designation)
    3. Verify construction is per design data

4. Entering and leaving air conditions (D.B. and W.B.)
5. Entering and leaving water temperature
6. GPM
7. CFM
8. Water temperature rise or drop
9. Air temperature rise or drop
10. Water pressure drop
11. Air pressure drop
12. Capacity in BTU per hour

4. Water Chilling Unit:

a. Installation Data:

1. Equipment schedule identification
2. Location in building
3. Manufacturer and model
4. All nameplate data
5. Nominal Tons
6. Motor HP, voltage, cycles, phase, and full load amps, kw
7. Part load amperes at 15%, 30%, 45%, 60%, 75%, 90% and 100% chiller load
8. GPM - evaporator and condenser
9. Water pressure drop - evaporator and condenser
10. Entering and leaving water temperature - evaporator and condenser
11. Refrigerant

b. Recorded Data (Evaporator and Condenser):

1. Date and time of readings
2. GPM
3. Water pressure drop
4. Entering and leaving water temperature
5. Operating amps and volts (for each leg)
6. Capacity in tons

c. Recorded Data (Air-Cooled Condenser):

1. Date and time of readings
2. CFM
3. Condenser pressure and temperature
4. Entering and leaving air temperature (D.B.)

        5. Four sets of recorded data shall be taken at 1/4, 1/2, 3/4, and full load.
        6. Capacity in tons

5. Domestic Water System:

    a. Balancing and Recorded Data:

        1. Adjust balance valves on recirculation lines to obtain equal temperature (plus or minus 2°F) in each leg of system.
        2. Record temperature of each leg of recirculation system and temperature at the recirculation pump.
        3. Record leaving water temperature of hot water heater(s).

6. Cooling Tower:

    a. Installation Data:

        1. Equipment schedule identification
        2. Manufacturer and model
        3. All nameplate data
        4. Motor HP, voltage, cycles, phase, and full load amps
        5. GPM
        6. CFM
        7. Water pressure drop (closed towers)
        8. Nozzle pressure (open towers)
        9. Entering and leaving water temperature
        10. Location on site
        11. Pan heater capacity - amps, voltage, phase

    b. Recorded Data:

        1. GPM
        2. CFM
        3. Water pressure drop
        4. Entering and leaving water temperature
        5. Operating amps and volts (for each leg)
        6. Ambient entering and leaving air conditions, db and wb (50 feet upwind of cooling tower)
        7. Capacity in BTU per hour (air)
        8. Capacity in BTU per hour (water)

3.8 SPECIAL SYSTEMS DATA

A. Report: The certified report shall include the data listed below.

B. Smoke Tests: After air and water balancing is completed, smoke tests shall be performed across all doors as directed by the Test Engineer (Division 17). Adjust (and record) air quantities as necessary to obtain code required pressure relationships as directed by the Engineer. Provide smoke gun and smoke.

3.9 FINAL TESTS, INSPECTION, AND ACCEPTANCE

A. Capacity and Performance Tests: Make tests to demonstrate that capacities and general performance of systems comply with contract requirements.

B. Retests: The testing agency shall recheck random selections of up to 10% of the data recorded in the balancing report in the presence of the Engineer. The balancing report will be automatically rejected if more than 20% of the rechecked readings deviate more than 10% of the recorded reading in the balancing report.

C. Marking of Settings: Following final acceptance of the balancing report, the settings of all valves, splitters, dampers, and other adjustment devices shall be permanently marked by the balancing agency, so that adjustment can be restored if disturbed at any time.

3.10 ACCEPTANCE CRITERIA

A. See criteria stated under Air Systems and Water Systems.

3.11 TEST PROCEDURES

A. Submit for approval detailed FPT procedures corresponding to the FPT criteria in Acceptance Criteria in this Section. FPT procedures shall be detailed test instructions, written with sufficient step-by-step information to allow a test to be repeated under identical conditions. List the value for all setpoints and inputs, positions of adjustable devices and acceptable results for each condition tested. Provide a unique alpha-numeric identification for each FPT procedure.

B. Submit for approval test procedure check-off sheets. Number each test procedure check-off item with the same number as the corresponding FPT procedure.

C. Demonstrate successful execution of FPT's listed under Acceptance Criteria in this Section. Sign-off each successful test and obtain the sign-off of the Commissioning Agent or other Owner-designated witness.

Appendix 4-13

SECTION 17600 - COMMISSIONING, ELECTRICAL SYSTEMS

GUIDE SPECIFICATION

The following guide specification is intended to be modified and included in the construction contract documents. Items to be modified will be decided by consultation involving the owner's project manager and the A/E. The A/E is expected to modify this and other specifications as necessary to accurately reflect commissioning requirements based upon specific systems, conditions, and requirements of the project.

PART 1 - GENERAL

1.1 DESCRIPTION

A. Provide commissioning and testing of the electrical systems.

B. Test and provide written certification that the entire electrical installation complies with contract documents, code and proper system operation. Perform acceptance tests in accordance with manufacturer's recommendations, NFPA 70B and International Electrical Testing Association (NETA) testing specifications NETA ATS-1991. It is the intent of the acceptance tests to assure that all electrical equipment, both Contractor and Owner supplied, is operational and within industry manufacturer's tolerances, complies with all applicable codes, and is installed in accordance with design specifications.

C. Electrical Testing Company. The following testing shall be performed by a third party ETC (Electrical Testing Company):

1. Service Grounding Test
2. Ground Fault Protection Systems Test
3. Transformers Dry Type
4. Motor Control Centers
5. Automatic Transfer Switch Test & Calibration
6. Switchboards, Switchgear
7. Molded-Case Circuit Breakers
8. Metering Test & Calibration
9. Metal Enclosed Bus Duct
10. Metal Frame Drawout Breakers
11. Power System Protective Device, Calibration
12. Variable Frequency Drives
13. Power Distribution Unit
14. Infrared Thermographic Scanning

1.2 RELATED WORK

A. Reference Sections 01650, 17100 and 17110 for primary commissioning requirements and responsibilities.

B. Reference Section 16995 for contractor requirements in support of the commissioning process. Refer to Division 16 specifications and plans and contractor shop drawings for system configuration and details of required construction.

1.3 TEST PERFORMANCE RESPONSIBILITY

A. The Test Engineer shall be responsible for the performance of all specified installation and commissioning tests.

B. The Test Engineer shall hire the services of a third party, ETC (Electrical Testing Company) to inspect and test all electrical equipment systems as specified in 17600 1.1 C above and other specialized equipment as specified in this section.

C. Any questions and concerns identified by the ETC shall be promptly addressed to the University Construction Coordinator.

PART 2 - PRODUCTS

2.1 ELECTRICAL TESTING COMPANY

A. Retain the services of Third Party ETC (Electrical Testing Company) that is qualified to test electrical equipment, and is an approved testing company by the Washington State Department of Labor and Industries. The ETC shall not be associated with the manufacturer of equipment or systems under test. Approved companies: Electro-Test, Westinghouse Engineering Service (for equipment not manufactured by Westinghouse), Asset.

B. ETC shall prepare test reports on the systems they test.

2.2 TEST EQUIPMENT

A. All shall be furnished by and remain property of the contractor. The following test equipment shall be provided and shall include as a minimum:

1. Amprobe
2. Voltmeter
3. Circuit Tracer

4. Power Factor Meter
5. Dranetz 901 or equal
6. Insulation resistance tester
7. Earth ground resistance tester
8. Circuit breaker tester
9. Thermovision infrared scanning equipment
10. Receptacle testers
11. 2 way radios

B. Test Instrument Traceability: The ETC shall have a calibration program which maintain all applicable test instrumentation within rated accuracy. The accuracy shall be traceable to the National Institute of Standards and Technology (NIST) in an unbroken chain. Instruments shall be calibrated in accordance with the following frequency schedule and dated calibration labels shall be visible on all test equipment:

1. Field instruments: 6 months maximum
2. Laboratory instruments: 12 months
3. Leased specialty equipment: 12 months (where accuracy is guaranteed by lessor)

PART 3 - EXECUTION

3.1 CONSTRUCTION OBSERVATION BY TEST ENGINEER

A. Obtain and review design documents for overall design intent and the overall required systems configurations.

B. Obtain and review shop drawings and submittals for installation criteria and the required construction details, as they support and further define the systems features.

C. The Test Engineer shall make general inspections at the job site and shall review the following for configuration, quality of construction, adherence to design requirements, and conformance with shop drawings and submittal information.

1. Service entrance switchboard
2. Main distribution switchgear, substations
3. Sub-distribution panels
4. Branch circuit panelboards
5. Motor control centers
6. Bus duct
7. Distribution transformers
8. Ground systems

9. Variable frequency drives
10. Power distribution units

D. The Test Engineer shall make general inspections at the job site and shall also review the following:

1. Assembly of the accessory equipment, and the interconnecting wiring for control circuits and fire alarm interface.

2. General Inspection of: Appearance, finish, alignment of doors, covers and similar parts; quality of workmanship; possible shipping and other damage; missing, broken or incorrectly applied devices; loose, or missing accessories, bushings, or hardware; loose or broken wires; proper installation of all equipment; equipment to verify that shop drawings and instructions have been shipped with all equipment and are available.

E. Electrical Nameplates: Review submittals for correct nameplates. Inspect and check all electrical equipment and devices above and below ceiling spaces for the correct nameplate. Prepare and submit checklist that identifies each electrical device with a sign off column for Test Engineer's initials.

F. Fire Stopping. Inspect all raceways for proper installation of fire stopping after installation of voice, data, video, audio, and security cables.

G. Support of Electrical Equipment: Inspect and check all electrical equipment for support and seismic bracing. Inspect and check light fixture seismic wires.

H. Emergency Off Switches: Test all emergency off switches and verify shut down and reset of equipment.

I. Spare Fuses: The Test Engineer shall inspect and verify spare fuse inventory as specified by Section 16180.

J. Lighting. Verify operation of all lamps one week prior to substantial completion.

3.2 ELECTRICAL TESTING COMPANY

A. The Test Engineer shall deliver the following project documents to the ETC eight weeks prior to testing:

1. Division 16 Specifications
2. Electrical Floor Plans showing equipment to be tested.

3. Electrical one Line Diagrams
4. Submittals of Manufacturers Data and Shop Drawings including engineers review letter of all systems to be tested.
5. Coordination Study
6. Fault Current Study

B. The ETC shall prepare test reports including description of project, description of equipment tested, description of test, test results, conclusions and recommendations, retesting results and list of test equipment used and calibration date. Calibration shall be traceable to the National Bureau of Standards and shall not be more than 6 months since last calibration.

C. One copy of each test report shall be delivered directly to the electrical engineer and Owner within 7 calendar days of the test.

D. Insert a copy of each test report in the operation and maintenance manuals.

3.3 ACCEPTANCE CRITERIA

A. The primary purpose of this section is to witness and verify operation of electrical equipment and systems as shown on electrical drawings and as specified in Division 16 of the contract documents.

B. Each function and test shall be performed under conditions which simulate as close to an actual operating condition as possible. To that end the contractor shall provide all necessary materials and temporary system voltages, currents to simulate fault conditions on the system being tested in order to prove and verify proper operation. At satisfactory completion of all verified tests, the building electrical systems being tested shall be returned to the condition required by the contract documents as a complete and operational system.

C. Demonstrate to the Owner's Representative successful execution of the following FPT's (functional performance tests) in accordance with approved FPT procedures as described in Test Procedures.

3.4 RECEPTACLE AND DEVICE TEST

A. Receptacle Polarity Test: The Test Engineer shall test every receptacle installed or reconnected under this contract with a receptacle circuit tester. Tester shall test for open ground, reverse polarity, open hot, open neutral, hot and ground reversed, hot or neutral and hot open. Rewire receptacles with faults and retest. Submit test report signed by Test Engineer that performed the test.

B. Ground-Fault Receptacle Circuit Interrupter Tests: The Test Engineer shall test each receptacle or branch circuit breaker having ground-fault circuit protection to assure that the ground-fault circuit interrupter will not operate when subjected to a ground-fault current of less than 4 milliamperes and will operate when subjected to a ground-fault current exceeding 6 milliamperes. Perform testing using an instrument specifically designed and manufactured for testing ground-fault circuit interrupters. Apply the test to the receptacle. "TEST" button operation will not be acceptable as a substitute for this test. Replace receptacles that do not shutoff power with 5/1000 of an ampere within 1/40th of a second and retest. Submit test report signed by Test Engineer who performed this test.

C. Operational Tests: Demonstrate the operation of each switch, circuit breaker and other item of electrical control with the systems fully energized and operating. Each shall be demonstrated three times.

3.5 600 VOLT WIRING

A. Scope: The Contractor shall test all electrical feeders and exterior branch circuits whose operating voltage is 600 volts or less that are installed under this contract and exterior branch circuits. The Test Engineer shall verify tests and submit a test report.

B. Test for continuity of each circuit.

C. Test for grounds in each circuit which shall consist of the physical examination of the installation to ensure that all required ground jumpers, devices, and appurtenances do exist and are mechanically firm.

D. Perform a 500 volt megohm meter test on each circuit between the conductor and ground. The insulation resistance shall not be less than 2 megohms for circuits under 115V, 6 megohms between conductor and ground on those circuits (115V-600V) with total single conductor length of 2,500 feet and over, nor less than 8 megohms for those circuits (115V-600V) with single conductor length of less than 2,500 feet. If conductor fails test replace wiring or correct defect and retest.

E. Perform torque test for every conductor tested and terminated in an overcurrent device or bolted type connection; torque all connections per manufacturers recommendations and tabulate the results on a tabular form.

3.6 POWER SYSTEM TESTS

A. Scope. The Test Engineer shall inspect and test entire electrical systems provided by this contract to verify equipment and controls are correctly operating.

B. Load Balance Tests: Checks all panelboards for proper load balance between phase conductors and make adjustments as necessary to bring unbalanced phases to within 15% of average load.

C. Motor Tests: Check all motors for proper rotation and measure actual load current. Submit tabulation of motor currents for all motors 1 HP or more after the HVAC system has been balanced.

D. Phase Relationship Tests: Check connections to all new and existing equipment for proper phase relationship. During such check, disconnect all devices which could be damaged by the application of voltage or reversed phase sequence.

E. Transformer Taps: Connect all transformers at "Normal" tap. After facility is occupied for two weeks, measure the following voltages for each transformer:

1. Primary and secondary voltages at transformer.
2. Receptacle voltages at 2 receptacles or 2 light fixtures that are the longest distance (greatest branch circuits length) from the panelboard.
3. Forward list of reading by transformer to Engineer for evaluation.
4. Reconnect all taps as directed.

3.7 SERVICE GROUNDING TEST

A. Perform three point fall-of-potential tests on main grounding electrode system per IEEE Standard No. 81, Section 9.04. Maximum resistance to ground shall be less than 5 ohms. If this resistance cannot be obtained with the ground system shown, notify the Architect immediately for further instruction.

B. Perform the two-point method test per IEEE Standard 81, Section 9.03 to determine the ground resistance between the main ground system and all major electrical equipment frames, system neutral, and/or derived neutral points. Resistance shall be no greater than 5 ohms.

C. Confirm that the neutral is grounded only at the service equipment by removing the service neutral grounding conductor and meggering the neutral bus.

D. Take ground readings as follows:

1. Phase I. Prior to connection of exterior ground system to building equipment or lightning protection down conductors.
2. Phase I. Prior to building occupancy, after connection to building ground system.
3. Retest exterior ground system after Phase II exterior ground system is intertied to Phase I system.
4. Phase II. Prior to building occupancy after connection to building ground system.
5. Phase III. Prior to building occupancy after ground system is complete.

3.8 GROUND FAULT PROTECTION SYSTEMS TESTS

A. Scope. Test all ground fault systems provided by this contract.

B. Prior to test:

1. Inspect neutral main bonding connection to assure:
    a. Zero sequence system is grounded upstream of sensor.
    b. Ground connection is made ahead of neutral disconnect link.
    c. Ground strap systems are grounded through sensing device.
    d. Verify ground electrode conductor(s) for proper size and connection.
2. Inspect control power transformer to insure adequate capacity for system.
3. Monitor panels (if present) shall be manually operated for:
    a. Trip test.
    b. No trip test.
    c. Non-automatic reset.
    Proper operation and test sequence shall be recorded.
4. Zero sequence systems shall be inspected for symmetrical alignment of core balance transformers about all current carrying conductors.
5. Ground fault system integral to the circuit breaker will have its current sensors and neutral sensor inspected for proper polarity.

6. Ground fault device circuit nameplate identification shall be verified by device operation.

7. Pickup and time delay settings shall be set in accordance with engineer's instructions or as shown.

C. Electrical Test

1. System neutral insulation resistance shall be measured to insure no shunt ground paths exist, neutral-ground disconnect link shall be removed, neutral insulation resistance measured and link replaced.

2. The relay pickup current shall be determined by current injection at the sensor and the circuit interrupting device operated.

3. The relay timing shall be tested by injecting one hundred fifty percent (150%) and three hundred percent (300%) of pickup current into sensor. Total trip time shall be electrically monitored.

4. System operation shall be tested at fifty-seven percent (57%) rated voltage.

5. Zone interlock systems shall be tested by simultaneous sensor current injection and monitoring zone blocking function.

D. Test Parameters

1. System neutral insulation resistance shall be two (2) megohm or greater.

2. Relay pickup current shall be within ten percent (10%) of device dial of fixed setting.

3. Relay timing shall be in accordance with manufacturer's published time-current characteristic curves.

3.9 TRANSFORMERS DRY TYPE

A. Test dry type transformers.

B. Visual and Mechanical Inspection

1. Test dry type transformers per the following procedures:

   a. Inspect for physical damage, proper installation, anchorage and grounding.

b. Verify transformer is supplied and connected in accordance with contract documents.

C. Electrical Tests

1. Perform insulation resistance tests winding-to-winding and winding-to-ground.

D. Refer to Section 17600-3.6E above.

3.10 MOTOR CONTROL CENTERS

A. Test motor control centers provided by this contract.

B. Visual and Mechanical Inspection

1. Inspect for physical damage and code violation.
2. Inspect for anchorage and grounding.
3. Compare overload heaters with motor full load current.
4. Compare starter size with motor horsepower.
5. Verify that correct heaters are installed in overload relays.

C. Electrical Tests

1. Measure overload time delay by primary current injection at three (3) times motor full load current.
2. Perform operational tests on each starter.
3. Measure insulation resistance of line bus phase-to-phase and phase-to-ground.

3.11 MOLDED-CASE CIRCUIT BREAKERS

A. Scope. Test all circuit breakers 100 amps and over.

B. Inspect each breaker, operate manually, and electrically. Test shunt trips and alarm devices manually and electrically.

C. Adjust breaker trips to settings furnished by the coordination study and verify settings of the manufacturer's rating by passing controlled current through the trip devices. Record values and report deficiencies. The trip characteristics when adjusted to setting parameters shall fall within the manufacturer's published time - current characteristics tolerance band.

D. Circuit Breaker Electrical Tests

1. Contact resistance shall be measured.
2. Time-current characteristic tests shall be performed by passing three hundred percent (300%) rated current through each pole separately. Trip time shall be determined.
3. Instantaneous pickup current shall be determined by run-up or pulse method. Clearing times should be within four (4) cycles or less.
4. Insulation resistance shall be determined pole to pole, across pole and pole to ground and across open contacts. Test voltage shall be 1000 volts D.C.
5. Check trip unit reset operation.

3.12 SWITCHBOARDS

A. Scope. Test all switchboards.

B. Inspect equipment and each breaker, fused switch and report installation or shipping damage, loose material, shipping blocks, contamination or unfavorable environmental conditions that must be corrected. Check equipment for operation of doors, security of mounting. Report deficiencies.

C. Check the equipment ground and record the number and size of ground bus and straps. Report deficiencies.

D. Inspect the bus assembly for deficiencies and torque test all bolted connections. Test insulation of each bus phase-to-phase and phase-to-ground and all control circuits to ground with a suitable megohmeter. Record values and report deficiencies.

E. Inspect for proper identification of protective devices.

F. Surge Arrestors

1. Test surge arrestors per the following procedures:

   a. Visual and Mechanical Inspection

      1. Inspect for physical damage, such as chipped or fractured porcelain.
      2. Inspect ground and discharge counter connections for integrity.

2. Electrical Tests

   a. Perform ground continuity test to ground grid system.

3.13 AUTOMATIC TRANSFER SWITCHES

A. Scope. Test Automatic Transfer Switches.

B. Visual and Mechanical Inspection

1. Inspect for physical damage, anchorage and grounding.
2. Perform manual transfer operation.
3. Clean and lubricate transfer mechanism as required. Check alignment and operation in accordance with manufacturer's instructions.
4. Verify proper operation of all interlocks.
5. Perform bypass and isolation functions.

C. Electrical Tests

1. Monitor and verify correct operation and timing of the following applicable items:

    a. Normal voltage sensing relays.
    b. Emergency voltage sensing relays.
    c. Test switch.
    d. In-phase monitor.
    e. Time delay upon transfer.
    f. Alternate voltage sensing relay.
    g. Interlocks and limit switch function.
    h. Timing delay and re-transfer upon normal power restoration.
    i. Contact resistance shall be measured across main contacts.

D. Perform insulation resistance tests phase-to-phase and phase-to-ground with switch in both source positions.

E. Set and calibrate in accordance with specifications:

1. Voltage sensing relay.
2. Frequency sensing relay.
3. Transfer time delay relay.

3.14 METERING TEST & CALIBRATION FOR METERS

A. Scope: Test all analog and digital meters provided by this contract.

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B. Visual and Mechanical Inspection

1. Examine all devices for broken parts, shipping damage, and tightness of connections.
2. Verify that meter types digital scales, and connections are in accordance with manufacture's drawings and specifications.

C. Instrument Transformers

1. Test transformer polarity electrically
2. Verify connection at secondary CT leads by driving a low current through the leads and checking for this amount at applicable devices
3. Confirm transformer ratio by primary current injection
4. Measure insulation resistance primary-to-ground, secondary-to-ground and primary-to-secondary.
5. Overpotential test primary insulation
6. Measure potential transformer ratio.

D. Metering and Instrumentation

1. Calibrate all analog meters at midscale
2. Calibrate watt-hour meter to one-half percent
3. Verify all instrument multipliers
4. Verify operation of each installed function (volt amps, etc.) on digital meters.
5. Determine accuracy at 50/75/100% of full scale for digital meters for each function.
6. Verify operation of alarm contacts if installed.

E. Verify and test operation of electronic metering communication links.

3.15 METAL ENCLOSED BUS DUCT

A. Scope: Test metal enclosed bus duct provided by this contract per the following procedures:

B. Visual and Mechanical Inspection

1. Inspect bus for physical damage and proper connection. Clean interior and insulators where applicable.
2. Inspect for proper bracing, suspension, alignment and enclosure grounding.
3. Check tightness of bolted joints by calibrated torque wrench.

C. Electrical Tests

1. Measure insulation resistance of each bus phase-to-phase and phase-to-ground for one (1) minute.
2. Inspect all accessible bus joints and cable connections by infrared scanner with maximum load to detect loose of high-resistance connections and other circuit anomalies.

3.16 SWITCHGEAR AND SWITCHBOARD ASSEMBLIES 1200A OR GREATER

A. Perform complete inspection for assembly, fit, anchoring and grounding. Inspect the bus assembly for deficiencies and torque test all bolted connections.

B. Perform insulation resistance test on each bus section, phase-to-phase, and phase-to-ground, and on control wiring. minimum test voltage and insulation resistance shall be as follows:

TABLE 16000.1

Voltage Rating	Minimum Test Voltage	Minimum Insulation
0 - 250 V	500 V DC	25
250 - 600 V	1,000 V DC	100
601 - 5,000 V	2,500 V DC	1,000
5,001 - 15,000 V	2,500 V DC	5,000

C. Existing EEB Substation PCM-E00-No. 1. The existing substation will be relocated. Inspect and perform preventative maintenance on substation. Test all protective devices. Inspect the bus assembly for deficiencies and torque test all bolted connections. Verify bonding and grounding connections. Prepare testing report and note deficiencies.

3.17 METAL FRAME, DRAW-OUT AIR CIRCUIT BREAKERS

A. Perform visual and mechanical inspections per NETA.

B. Perform electrical tests per NETA.

3.18 POWER SYSTEMS PROTECTIVE DEVICE AND CALIBRATION

A. Scope: It is the intent of these tests to assure all protective devices are operational, correctly applied, within industry and manufacturer's tolerances, and installed in accordance with the specifications. This effort should minimize the damage caused by any electrical failure. The ETC shall verify and certify that the electrical system and electrical equipment configuration matches the contract documents, electrical equipment shop drawings, and the electrical system coordination study recommended settings.

B. Adjustments, Settings and Modifications: The ETC shall calibrate necessary field settings, adjustments and minor modifications to conform with the coordination study without additional cost. (Examples of minor modifications are trip sizes within the same frame, the time curve characteristics of induction relays, ranges etc.) Adjust protective devices to the values provided in the coordination study. Test the minimum pickup and delay, ground fault pickup and delay. Demonstrate the zone interlock feature. The trip characteristics, when adjusted to setting parameters, shall fall within the manufacturer's published time-current characteristic tolerance.

C. Certifications: Two weeks prior to final inspection, the ETC shall deliver four copies of the following certifications to the Owner's representative:

1. That the protective devices have been adjusted and set in accordance with the approved protective device study.
2. That tests and settings have been witnessed by the Test Engineer.

3.19 VARIABLE FREQUENCY DRIVES

A. Scope: Test variable frequency drives.

B. Mechanical and Visual Inspection

1. Visually inspect for obvious indications of physically damaged or overheated components.
2. Verify all static switch and jumper settings are applicable to the input and load.
3. Inspect for loose terminations.
4. Verify stop and safety circuits are properly terminated.
5. Verify the motor terminations are consistent with the drive output.

C. Electrical Tests

1. Test and record the line volts and amps. Observe for balance within 10%.
2. Inspect for proper jumper or switch settings for given drive parameters if so equipped.
3. If possible, start and run the drive while observing the test metering or fault indicators if so equipped.

4. Test and record output volts and amps while the drive the drive is at 25%, 50%, and 100% speed and attached load. Observe for balance and within manufacturers' specifications.
5. Set adjustable parameters to match the settings provided.
6. Activate the various safety devices when possible to ensure proper operation.
7. Record harmonic distortion at two levels of common coupling, each level is to be at the next upstream feed.
8. After completion of air balancing, record final drive settings of the vfd's.

3.20 POWER DISTRIBUTION UNIT

A. Scope. Test power distribution units.

B. Test transformer per Section 17600 - 3.9 above.

C. Test circuit breakers per Section 17600 - 3.11 above.

D. Test shunt trip, alarms, and emergency off stations.

3.21 INFRARED THERMOGRAPH SCANNING:

A. In general, the scan shall be made when the equipment is energized and is operating at its normal capacity. It is intended that the scan be made after the equipment has been in full operation as follows:

Phase I:	One year after occupancy
Phase II:	One month after occupancy

B. Test equipment, miscellaneous tools, and materials shall be transported properly, moved, and set up by trained personnel. Equipment used in testing shall be capable to perform all recommended procedures required by the apparatus and related equipment. All test equipment shall have certification of calibration and be in working order.

C. All hot spots shall be marked, identified and an infrared thermographic scanning report prepared and furnished to the Test Engineer.

D. The report shall contain infrared photos of trouble spots with temperature readings.

E. All sources of heating problems shall be promptly reported to the owner for corrective action by the Division 16 contractor.

F. Infrared scanning equipment shall be an AGA (or approved equal) thermovision set capable of viewing an entire bus or equipment assembly at one time and have a sensitivity of 0.2° C. with a liquid nitrogen reference.

3.22 TEST PROCEDURES

A. Submit for approval detailed FPT procedures corresponding to the FPT criteria in Acceptance Criteria in this Section. FPT procedures shall be detailed test instructions, written with sufficient step-by-step information to allow a test to be repeated under identical conditions. List the value for all setpoints and electrical values and acceptable results for each condition tested. Provide a unique alpha-numeric identification for each FPT procedure.

B. Submit for approval test procedure check-off sheets. Number each test procedure check-off item with the same number as the corresponding FPT procedure.

C. Demonstrate successful execution of FPT's listed under Acceptance Criteria in this Section. Sigh-off each successful test and obtain the sign-off of the Commissioning Agent or other Owner-designated witness.

3.23 SCHEDULE

A. Perform all testing after installation and before energizing. All systems shall pass tests prior to placing in service.

B. The Test Engineer shall submit to the University Construction Coordinator a schedule of all tests to be performed one month prior to the scheduled performance of the first test. Items to include summary of project, description of test, conclusions and recommendations, appendix including sample test forms.

C. Confirm test schedule with UW Construction Coordinator one week prior to test. The Test Engineer shall coordinate the test schedule so that the UW Plant Engineering can witness all testing.

D. The Test Engineer shall deliver to the construction coordinator, UW Plant Engineering, and the engineer, within 5 working days of test the test results. The owner shall have the tests for a two week review prior to energization.

3.24 TEST REPORTS

A. The ETC shall prepare test reports including description of project, description of equipment tested, description of test, test results, conclusions and recommendations, retesting results and list of test equipment used and calibration date.

B. Insert a copy of each test report in the operation and maintenance manuals.

3.25 RETESTING

A. Any fault in material or in any part of the installation revealed by these tests shall be investigated, replaced or repaired by the Contractor and the same test repeated by the ETC at Contractor's expense until no fault appears.

3.26 LABELS

A. Upon completion of the tests a label shall be attached to all tested devices. These labels shall indicate date serviced and the ETC.

END OF SECTION

Appendix 6-1

Request for Professional Services
Submittal Date: 9 June 1994

UNIVERSITY OF WASHINGTON
BUILDING COMMISSIONING

Submittals of qualifications will be received by the University of Washington for commissioning new buildings, with construction costs exceeding $10 million, which will begin construction during calendar years 1994 and 1995. Three potential projects are the School of Business Administration Addition (BA) (56,000 gsf), the Electrical Engineering/Computer Sciences Building (EE/CSE) (318,000 gsf), and the Henry Gallery Expansion/Renovation. These facilities variously include offices, classrooms, auditoria, state-of-the-art VAV air conditioning systems, laboratory utilities, chillers, cooling towers, etc. BA and EE/CSE will start construction during 1994. Henry Gallery will bid in summer 1995. Each construction period will be about 24 months. EE/CSE has a second phase which will require an additional 16 months.

Plans are available for review in the Plant Engineering Office located in Plant Operations Annex #6 at the University of Washington; although review prior to qualifications submittal is not required.

Preferred qualifications include a minimum of three years commissioning experience with VAV supply and exhaust ventilation systems, fume exhaust systems, chillers, cooling towers, laboratory utility services, DDC environmental control systems, controls interfaced with fire alarm systems, electrical substations, switchgear, breaker coordination, motor controls, variable frequency drives, energy conservation measures, etc.

All interested and qualified firms are invited to submit a statement of qualifications consisting of the following:

1. History of the company;
2. Commissioning expertise and capability;
3. Local experience over the last three years on projects of similar size and scope;
4. Reference contacts with telephone numbers;
5. Resumes of key management personnel and their positions;
6. List of personnel to be assigned to UW projects, their certifications and commissioning responsibilities;
7. Personnel rate schedule;
8. Location of the firm and proximity to the work site;
9. Professional liability insurance coverage including Errors and Omissions.

Submittals shall include three (3) copies each of a letter of interest, the above listed information, and completed SF 254 Form. University of Washington latest edition of Form SF 254 may be obtained by calling the Capital Projects Office (206) 543-5200.

The University of Washington is an affirmative action/equal opportunity employer and encourages minority and women owned firms to participate.

The University will interview at least two firms from those responding to this solicitation. Firms invited for interview will be required to present comprehensive evidence of commissioning documents developed for a project commissioned by the firm. Final selection, in each case, will be based upon the qualifications listed above, in comparison to the needs of the project, and the quality of the documents provided during the interview. Firms selected for final consideration will be notified on or about June 30, 1994.

Send submittals to: COMMISSIONING PROGRAM 1994
Plant Engineering Division
Plant Operations Annex 6 FG-0
Seattle, Washington 98195
Attn: John A. Heinz

Submittals must be received no later than 5:00 P.M. on June 9, 1994.

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May 19, 1994 and May 26, 1994

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Appendix 6-2

UNIVERSITY OF WASHINGTON
ENGINEERING SERVICES OFFICE
CONSULTANT SELECTION EVALUATION FORM

PROJECT: ______________________________

FIRM: ______________________ DATE: ____________

EVALUATOR: ______________________ SCORE: ____________

QUALIFICATION ITEMS	RATING						FACTOR	SCORE
	LO			AVG		HI		
Firm's range of experience with commissioning activities	0	1	2	3	4	5	5	____
Evidence of successful commissioning of projects of similar complexity and sophistication	0	1	2	3	4	5	5	____
Project Manager's experience with commissioning activities	0	1	2	3	4	5	5	____
Team members experience with commissioning activities	0	1	2	3	4	5	5	____
Firm's years of commissioning experience (>10=5; 6-9=4; 3-5=3; 1-2=1; 0=0)	0	1	2	3	4	5	4	____
Firm's experience consistent with UW requirements	0	1	2	3	4	5	4	____
Evidence of ability to develop comprehensive schedules, test procedures and check-off lists	0	1	2	3	4	5	4	____
Evidence of experience working cooperatively as Owner's agent with A/E firms, contractors, TAB firms, etc.	0	1	2	3	4	5	3	____
Evidence of familiarity with procedures required in public works environment and contracts	0	1	2	3	4	5	2	____
Evaluator's subjective reaction to firm's qualifications	0	1	2	3	4	5	5	____

TOTAL SCORE ____

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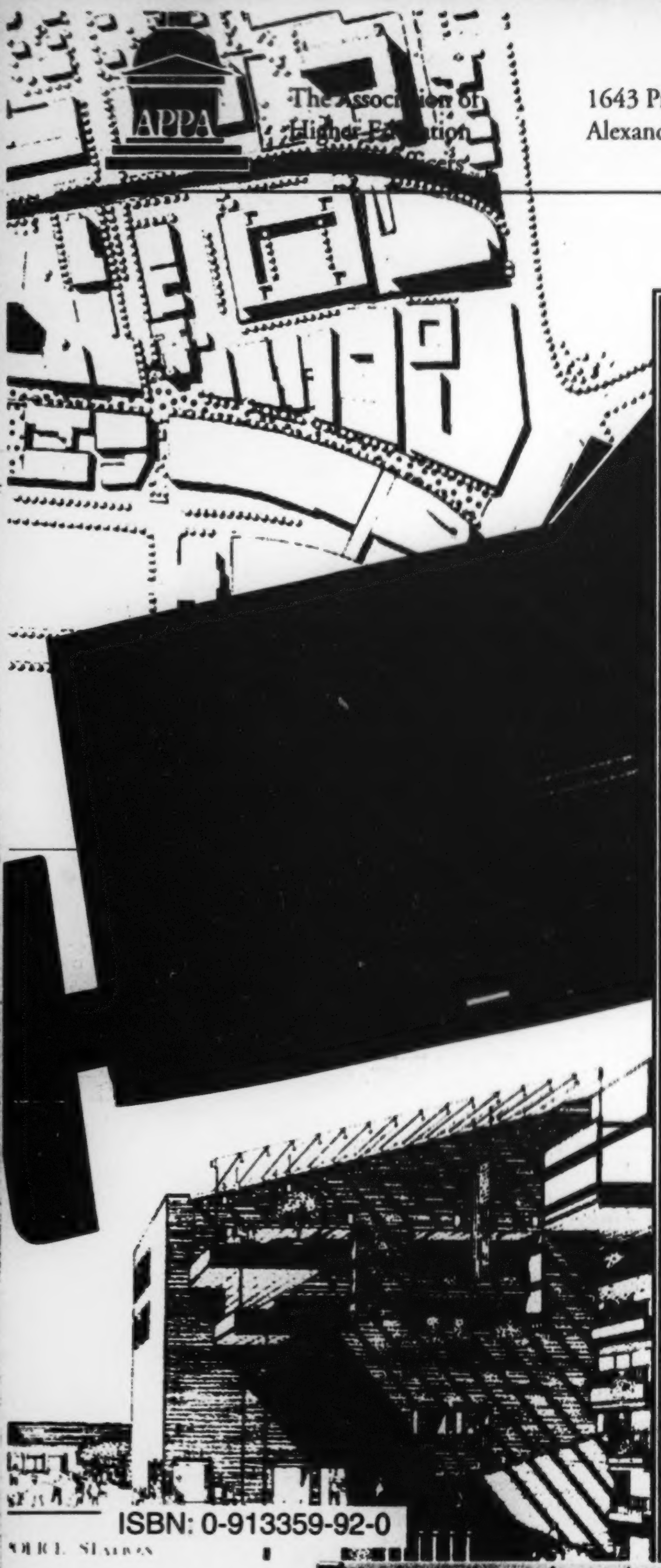

Today's new high tech buildings are complex, highly engineered entities requiring precise, comprehensive planning, design, and construction. The smallest variance in specifications or installation can result in malfunctions that may take months or years to diagnose, and thousands of dollars to remedy.

Author John A. Heinz, former director of engineering at a major research university, describes here a method for preventing such setbacks: building commissioning. Building commissioning shifts the responsibility for a properly functioning building to the contractors and subcontractors responsible for the design and construction of the building and its systems.

Heinz demonstrates how, through a system of thorough specification, clear performance requirements, and extensive pretesting, the chance of malfunctions can be dramatically cut.

Included are advice on selecting a commissioning agent, a detailed case study for a multimillion dollar research facility, and hundreds of pages of sample documents and specifications.

The Building Commissioning Handbook provides the tools to ensure that today's sophisticated building systems deliver on their promises.

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